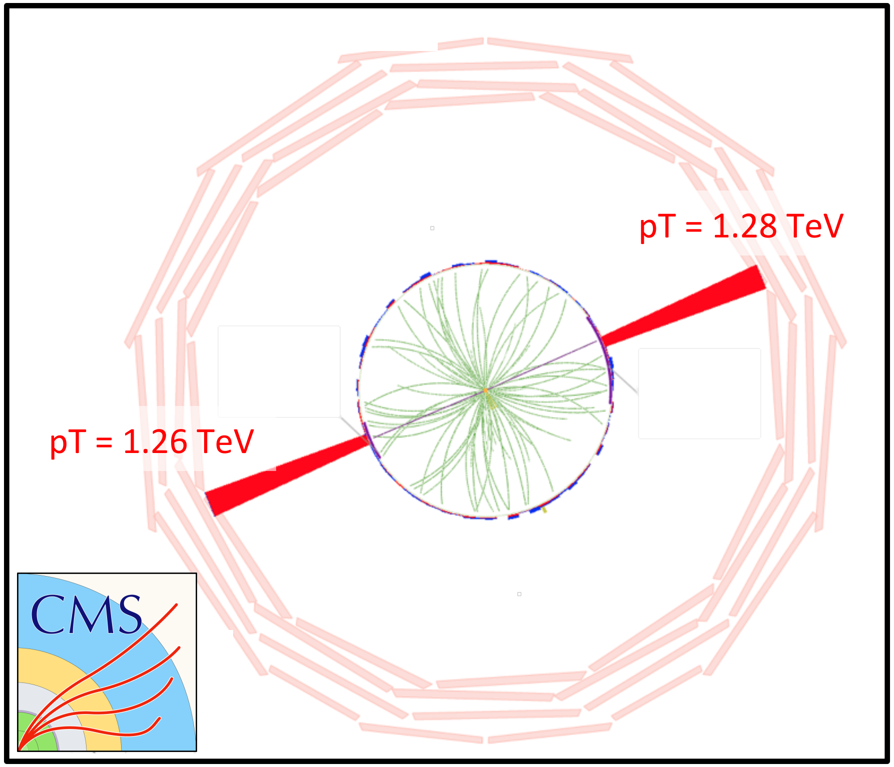
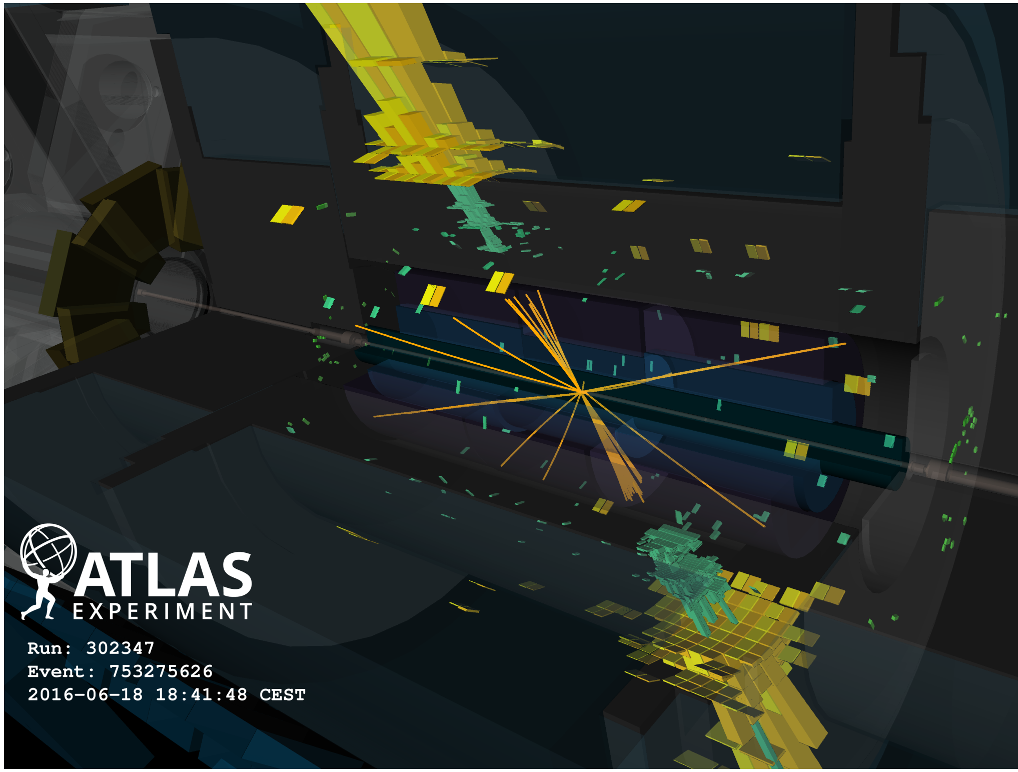
Experimental Overview

Digging Deeper- PITT PACC workshop 2017





High mass di-electron in CMS event 3TeV

High mass central dijet event 6.4 TeV

Marumi Kado
LAL, Orsay

University of Pittsburgh
February 23, 2017

Goals and Disclaimer

- Introduction to a great list of coming talks (mostly on direct searches at LHC)!
- Complete the picture (with a few measurements)
- Emphasize a few points:
  - How to dig deeper? (Make a manifesto for precision at LHC)
  - Where to dig? (Interaction with TH – PH community)

This talk will **mainly focus on results from the ATLAS and CMS collaborations published in 2016.**

It will not display the host of beautiful results from all experiments (ALICE, LHCb, ALFA, TOTEM, LHCf, MoEDAL).

Complete list of publications from ATLAS CMS

- ATLAS: https://twiki.cern.ch/twiki/bin/view/AtlasPublic
- CMS: http://cms-results.web.cern.ch/cms-results/public-results/publications
- LHCb http://lhcbproject.web.cern.ch/lhcbproject/Publications/LHCbProjectPublic/Summary_all.html
- ALICE http://aliceinfo.cern.ch/ArtSubmission/submitted
-

This talk will not cover future projects neither HL-LHC nor future colliders

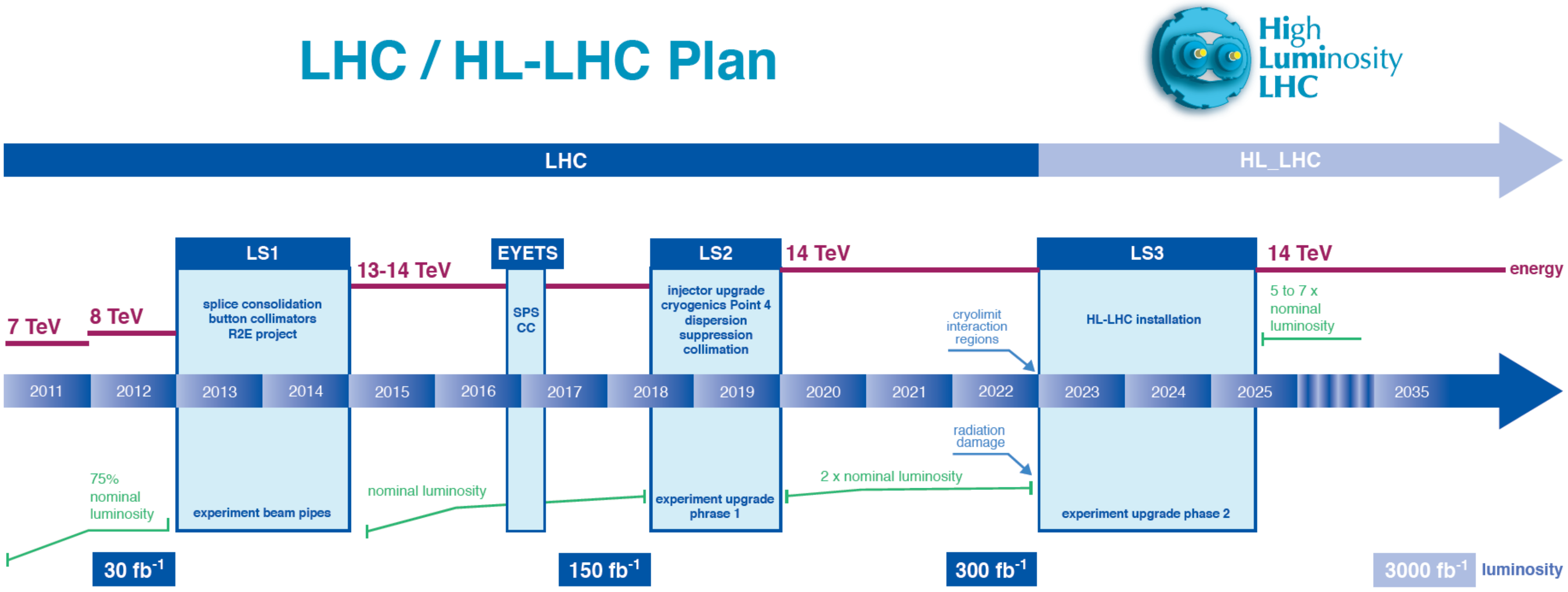
Where do we stand in the LHC Physic Program?

Initial Mission of the LHC:

- **The no-loose theorem**: Discover the Higgs boson or reveal strong dynamics in vector boson scattering
- **Probe the electroweak scale**: with direct searches for new phenomena beyond the Standard Model.
- **Probe the Standard model and higher scales indirectly**: Through CP-violation in Heavy Flavors, rare B decays, etc… Through precision measurements of Higgs couplings, standard EW parameters, anomalous couplings, etc…
- **Study strongly interacting matter at extreme energy densities**.

In all these areas the LHC is already an immense success

Machine Status (in a nutshell)



Where do we stand?

- 8th year of the (25 year) program. Reaching almost nominal centre-of-mass energy and surpassed nominal luminosity estimates.
- At the start of an Extended YETS: in particular to replace CMS inner pixel detector.

2016 Outstanding performance of the LHC

- Peak luminosity from 1.5 10^{34} $cm^{-2}s^{-1}$
- Integrated delivered luminosity of 40 fb^{-1}.

Reappraised goal for Run-2

New target 150 fb^{-1} in 2018.

Machine Status (in a nutshell)

2016 was declared a production year… and the operation team delivered!

With immediate noticeable changes in 2016:

- A lower β^* of 40cm instead of 80cm in 2015.
- A smaller bunch spacing of 25ns

(Some of) **the reasons behind the outstanding luminosity reach in 2016**:

- High machine availability (less UFOs, many fixes and tunings)
- High luminosity lifetime (tunes, couplings and bunch length)
- High peak luminosity (low emittance with BCMS, low beta*, and crossing angle)

For more details see talk by B. Salvant at the LHCC

Such a complex project encountered various issues, very prompt solutions were found: **Congratulations to the Machine operations and coordination teams!**

Possible goals for next year

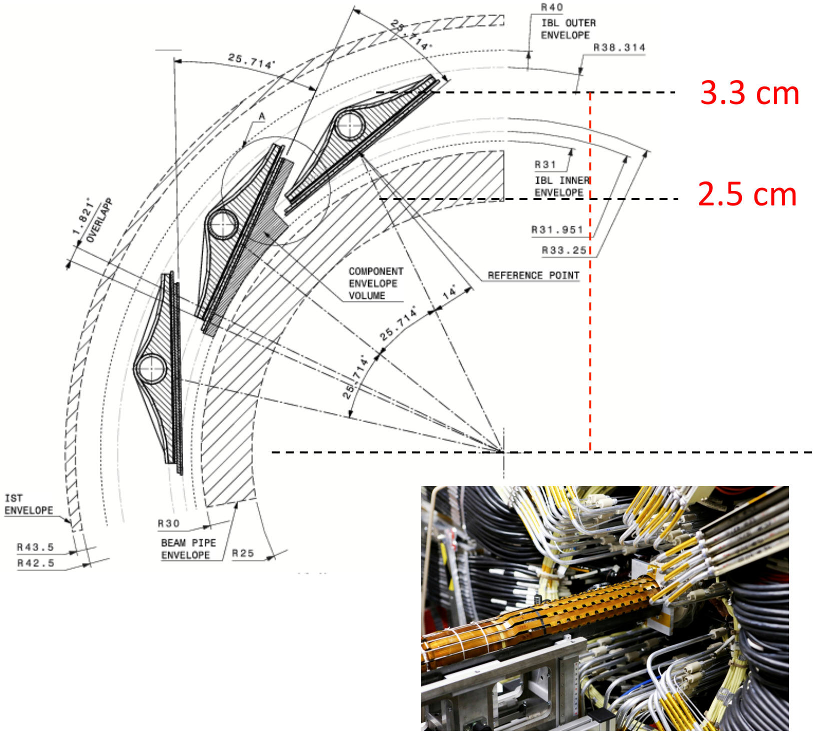
- Peak luminosity from 1.4 - 2 10^{34} $cm^{-2}s^{-1}$ (depending on BCMS scheme).
- Peak PU from 37 to 56.
- Integrated luminosity between 45 and 60 fb^{-1}.

Main Detector Improvements

Important changes in all areas of the experiment

ATLAS – Phase 0

- 4th innermost layer of pixels (3.3 cm, 2nd layer at 5.05 cm)
- Consolidation: Complete muon coverage, Luminosity detectors, Repairs (LAr and Tile), Beam Condition. Monitors
- Infrastructure: New Beam Pipe, Magnets and Cryogenic system, Muon Chamber shielding, New pixel services
- Trigger/DAQ: Increase max L1 rate from 75kHz to 100kHz, new Central Trigger Processor, Merge L2 and HLT farms, Additional SFOs for higher output rate.
- Topological L1 triggers
- Fast Track Trigger

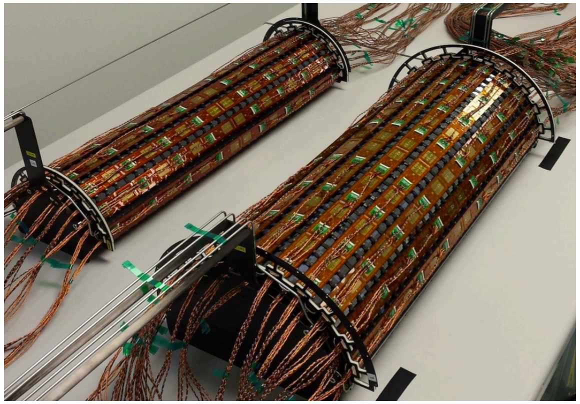


Inserted during LS1

CMS – Phase 0

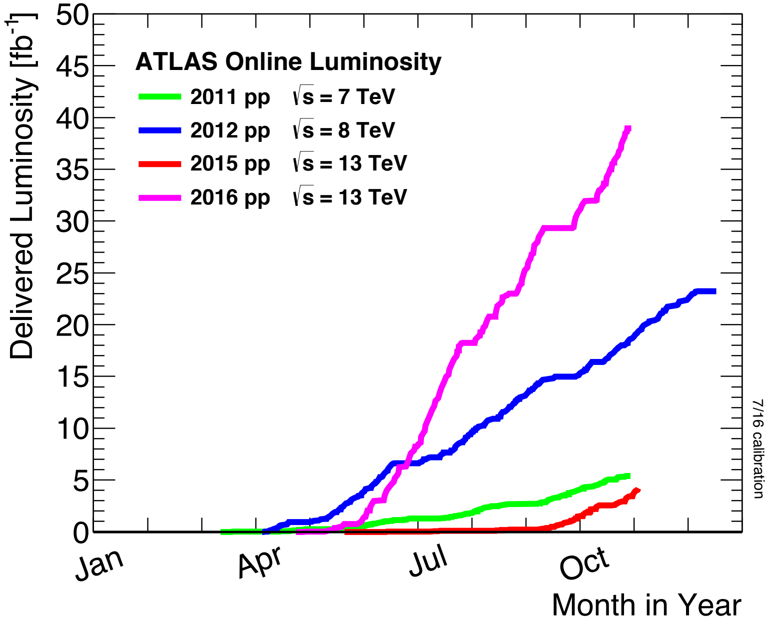
- Complete muon coverage
- Replace HCAL photodetectors
- During LS1 L1 Triger upgrade
- New Pixel detector: to be inserted during the EYETS
- L1 Trigger upgrade

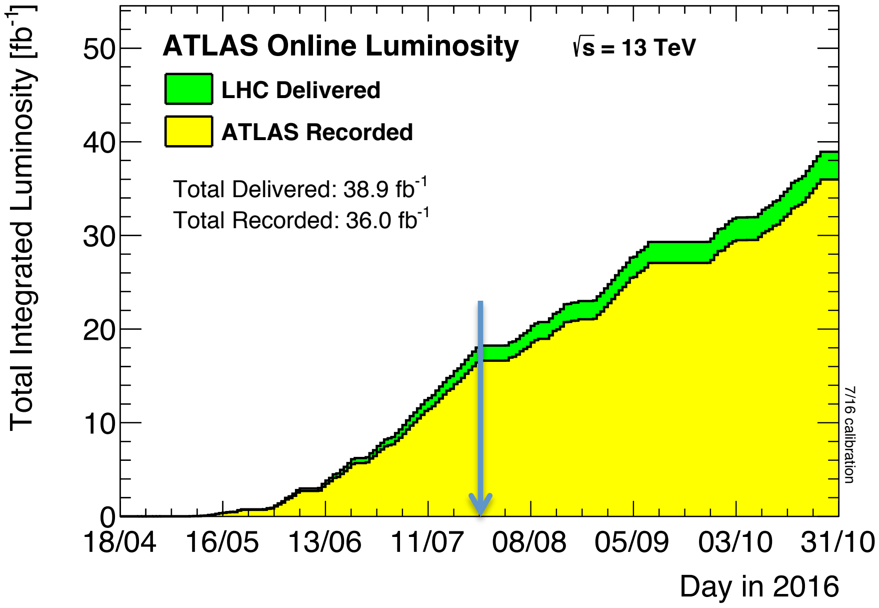
Both for ATLAS and CMS Reconstruction and analysis software are regularly updated.



To be inserted during EYETS

2016 Data





ATLAS and CMS Excellent data taking and data quality efficiencies:

- ATLAS has recorded 36.0 fb^{-1} and CMS 37.8 fb^{-1}.
- Pile-up conditions note that in 2015 – need to be careful to out-of time PU increase.

Data set for results ICHEP

Typically 10 -12 fb^{-1} (ATLAS and CMS)

Hopefully soon results with 36.0 fb^{-1} then…

Doubling time of luminosity is now O(1 year)

For the physics:

- Full 2015 O(30) x EPS 2015 / LP 2015 Luminosity
- ICHEP 2016 ~3 x Full 2015 Luminosity
- Full 2016 dataset ~ 3 x ICHEP 2016

Heavy Ion data

- PbPb collisions at centre-of-mass energies in excess of 1 PeV in 2015. Considerable stress on the performance of the reconstruction algorithms.
- pPb in 2016: Records luminosities obtained in pPb as well in 2016.

See Ben’s talk

Online typical Performance

HLT algorithms are typically asclose as possible to reconstruction level algorithms. Trigger menus are extremely complex including support items the ATLAS Run 2 menu has ~2000 items.

Photons

- Single photon threshold 140 GeV 20 Hz
- Two photon thresholds at 25 and 35 GeV 12 Hz

Electrons

- Single electron threshold 25 GeV 140 Hz
- Two electrons at 12 GeV 20 Hz

Muons

- Single muon trigger threshold 24-25 GeV (2 muons 6-6 GeV) 130 Hz
- Two muons 10 GeV 20 Hz

Jets

- Single jet trigger threshold 380 GeV 20 Hz

MET

- MET trigger threshold 90-110 GeV 60 Hz

Taus

- BDT based identification (70% eff. and ~50 rej.) similar to reconstruction level.
- Single tau 80 GeV 40 Hz

B-jets

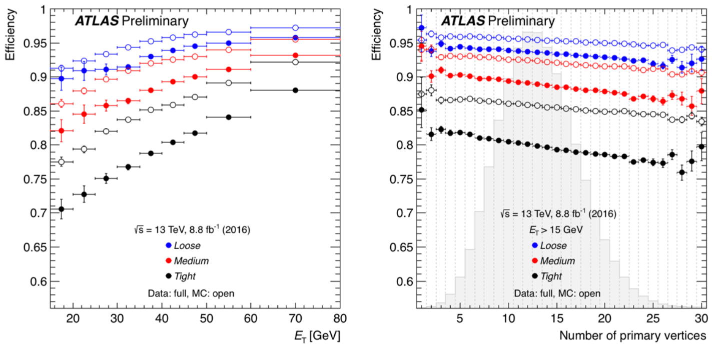
- HLT only, but allows to lower the trigger thresholds.
- MVA based algorithm similar to reconstruction level.
- Tracking is not precisely the same (take into account updates of conditions, in particular the alignment.
- One loose b threshold 225 GeV 35 Hz

Typical HLT unique rates

See Ben N’s talk

Reconstruction Performance

Example for ATLAS (similar for CMS)

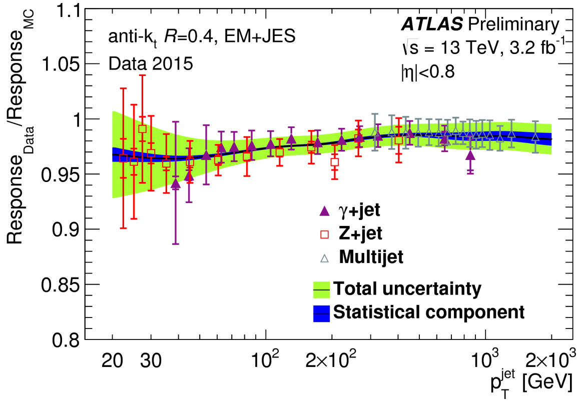


Electrons and photons

- Likelihood (cut) based ID for electrons (γ) and MVA-based calibration
- In-situ calibration using Z, W and J/Psi

Muons

- Excellent performance (with few sporadic muon chamber failures)
- In-situ calibration of energy and ID efficiency with Z (and J/Psi)

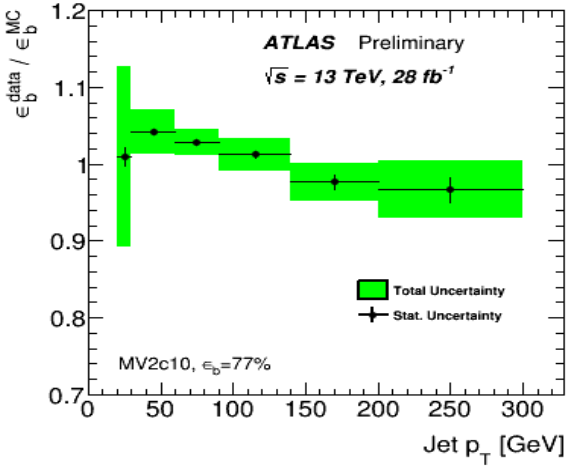


Jets

- Anti-kT algorithm from 0.4 to 0.7 used with detector noise cleaning cuts and track based variable to mitigate PU effect.
- JES in situ uncertainty reach ~1% level already (central and intermediate pT range) – using Z, γ and multi-jets.

MET

- Reconstruction use all calibrated objects and a track-based soft term



Taus

- BDT based identification (70% eff. and ~50 rej.)
- In-situ calibration based on Z events

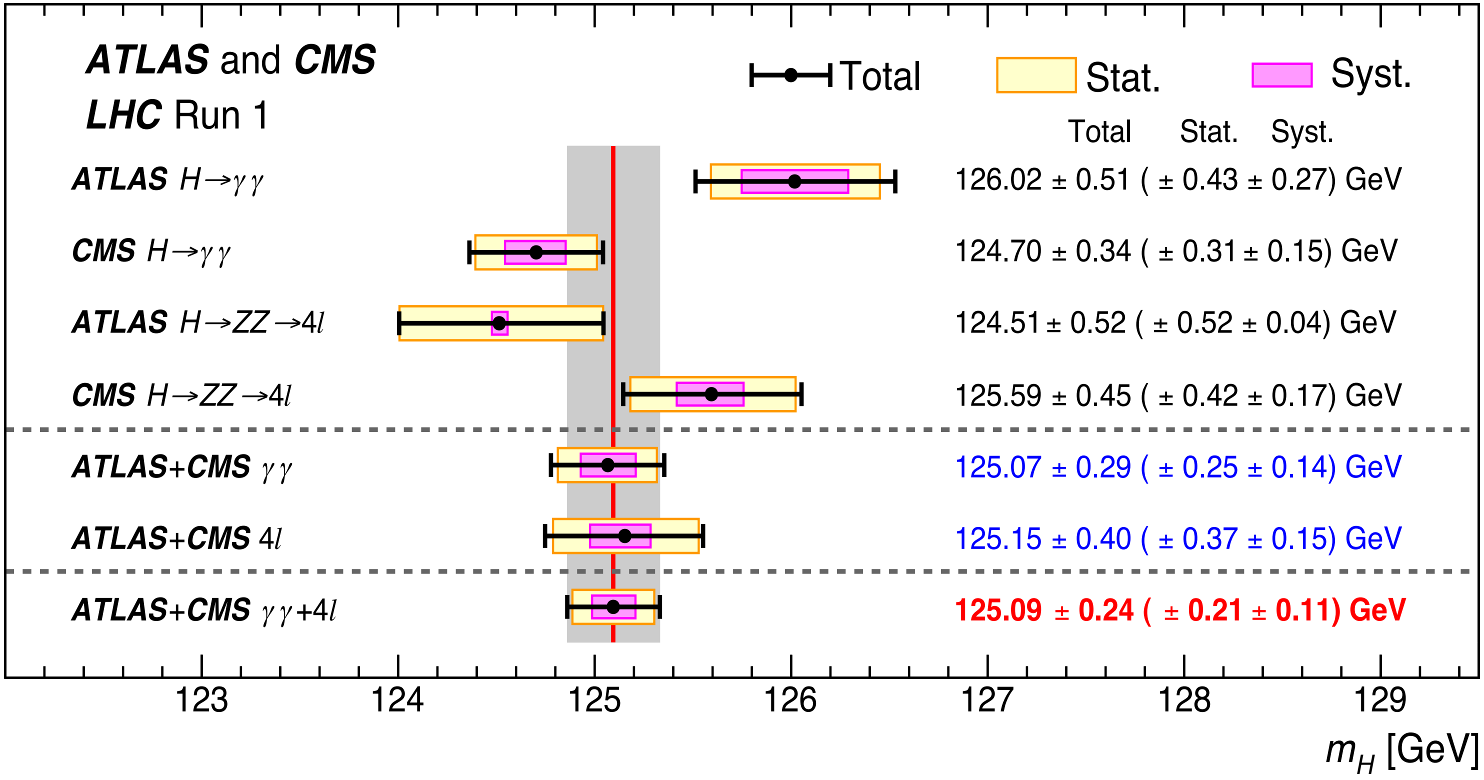
B-jets

- MVA based algorithm (77% eff., ~250 l-rej. and ~8 c-rej.)
- Improvement w.r.t Run 1 pT dependent but typically ~4 in rej.
- In-situ calibration of b-tag efficiency (using top events)

Reconstruction performance so far robust to PU

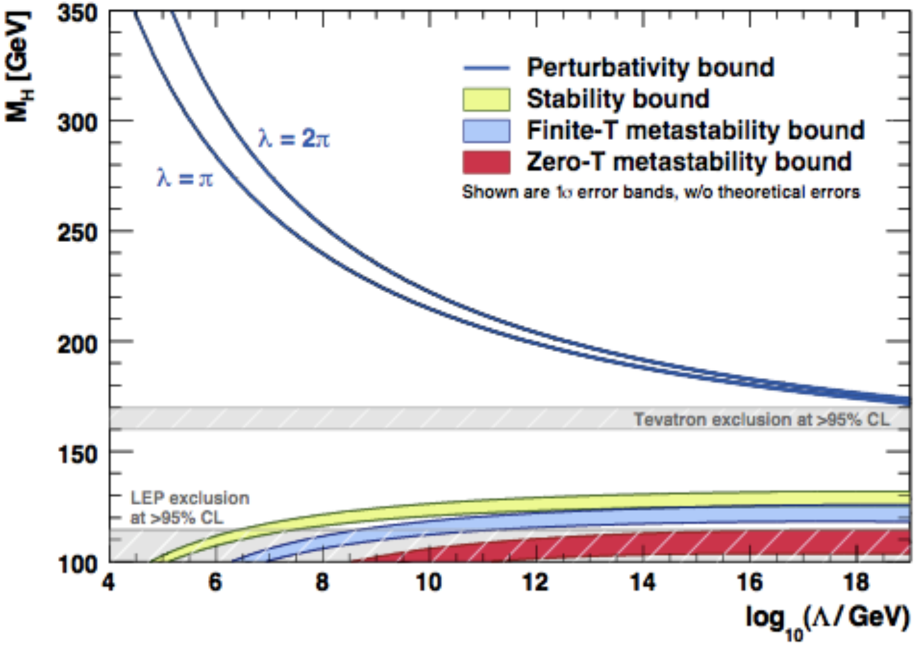
Higgs Mass Measurement

The fundamental new parameter that we learned is its mass (and if the Higgs potential is SM-like also its self coupling).



2 per-mille precision Measurement, until last week the most precise measurement a the LHC (combined ATLAS and CMS).

Implications (I) – TH consistency



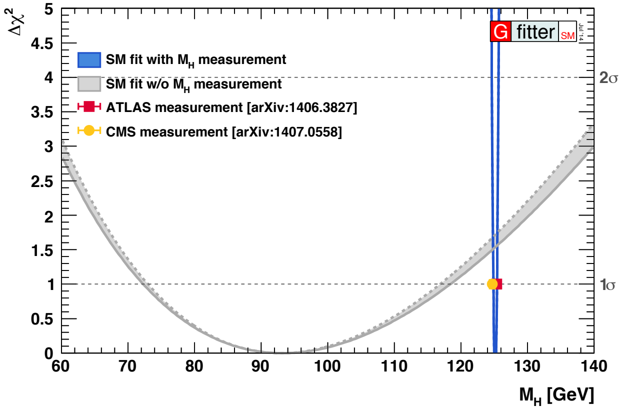
With the discovery of the Higgs, for the first time in our history, we have a self-consistent theory that can be extrapolated to exponentially higher energies.

Nima Arkani Hamed

From the running of the self coupling (in the SM There is no need (or indication) that to preserve vacuum stability and avoid Landau pole (triviality) new physics is needed.

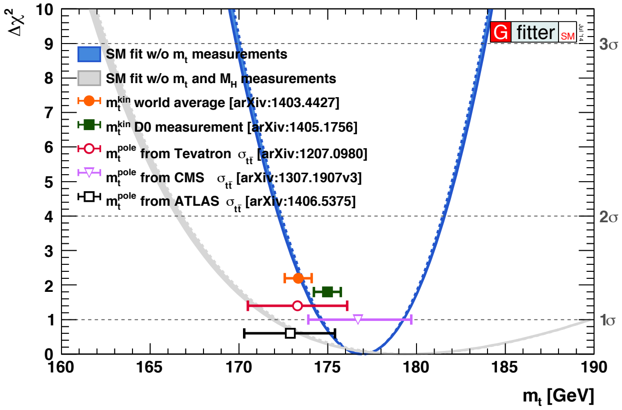
With the measured value of the Higgs boson mass and **the top mass**, the self-coupling of the Higgs is vanishing at the Planck scale (is there an underlying principle to this?).

Implications II – EW Fit



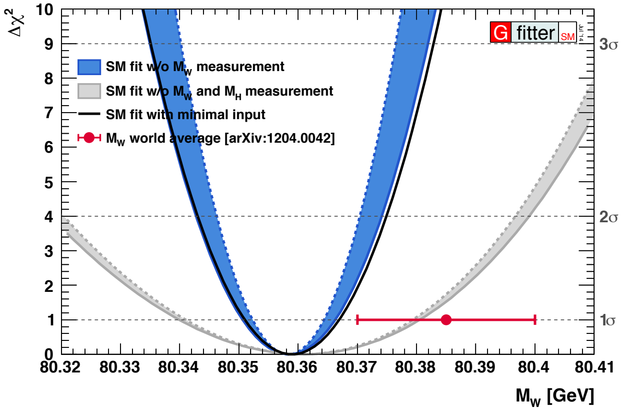
Higgs corrections are logarithmic in Higgs mass and yield indirect measurement in agreement with the direct one. Precise knowledge of the Higgs mass will not change this picture

$$\Delta\rho = -\frac{\alpha}{4\pi}\log\frac{m_H^2}{m_Z^2}$$



The larger corrections from the top and the knowledge of the Higgs mass yield a precise indirect constraint, however not competitive with the direct measurement.

$$\Delta\rho = \frac{\alpha}{\pi}\frac{m_t^2}{m_Z^2}$$



The knowledge of the Higgs mass has also improved the indirect W mass measurement at a precision (8 MeV) tice better than the WA (15 MeV) as of two weeks ago…

$$m_W^2\left(1-\frac{m_W^2}{m_Z^2}\right) = \frac{\pi\alpha}{\sqrt{2}G_F}(1+\Delta r)$$

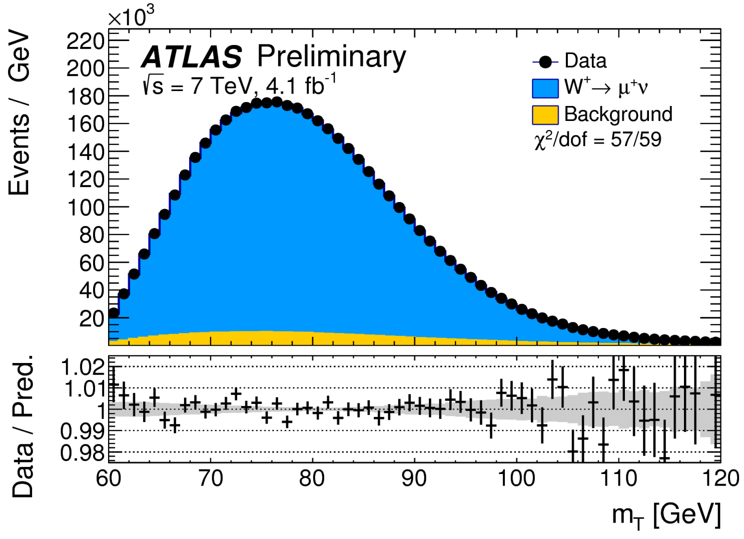
CERN-EP-2016-305

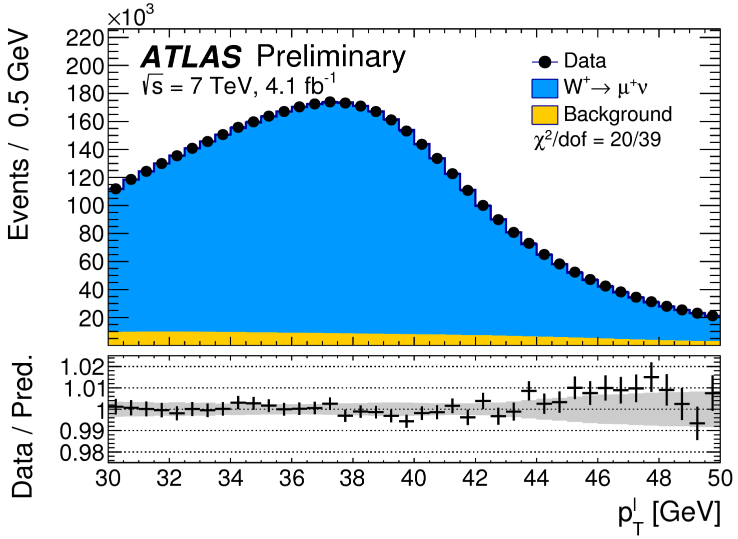
W Mass at the LHC

Milestone measurement presented in December last year!

Analysis strategy based on two kinematic distributions fitted in several categories

Decay channel	$W \to e\nu$	$W \to \mu\nu$
Kinematic distributions	p_{T}^{ℓ}, m_{T}	p_{T}^{ℓ}, m_{T}
Charge categories	W^{+}, W^{-}	W^{+}, W^{-}
$\lvert\eta_{\ell}\rvert$ categories	$[0, 0.6]$, $[0.6, 1.2]$, $[1.8, 2.4]$	$[0, 0.8]$, $[0.8, 1.4]$, $[1.4, 2.0]$, $[2.0, 2.4]$





Prediction

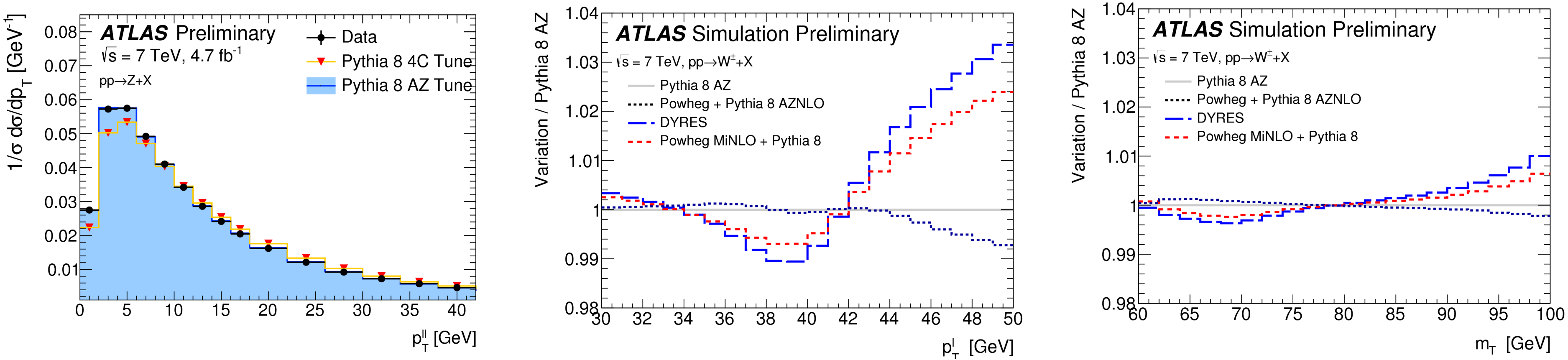
Prediction

- Reweighted fully simulated events using Powheg v1 – Pythia 8.170 – CT10 for HS (and CTEQ6L1 for PS) with AZNLO tune (QED ISR with Pythia 8 and FSR with Photos) – NLO EW effects not taken into account in baseline but uncertainty taken into account)
- Three steps reweighting procedure using factorized fully differential cross section:

$$\frac{d\sigma}{dp_1\,dp_2} = \left[\frac{d\sigma(m)}{dm}\right]\left[\frac{d\sigma(y)}{dy}\right]\left[\frac{d\sigma(p_T, y)}{dp_T\,dy}\left(\frac{d\sigma(y)}{dy}\right)^{-1}\right]$$
$$\left[(1+\cos^2\theta) + \sum_{i=0}^{7} A_i(p_T, y) P_i(\cos\theta, \phi)\right]$$

  - First reweight rapidity distribution to DYNNLO with CT10nnlo
  - Then at given rapidity reweight in pT to Pythia 8 AZ tune
  - Finally reweight to angular (A_i) coefficients estimated at $O(\alpha_s^2)$

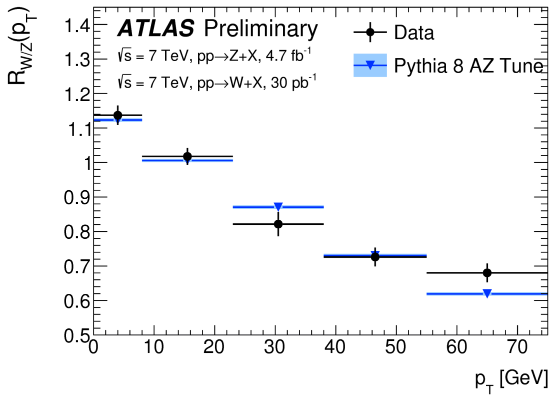
Reweighting procedure tested at particle level with different NNLO PDF sets (CT10 and NNPDF3.0) a MeV level (non-significant) variation on mW is observed.

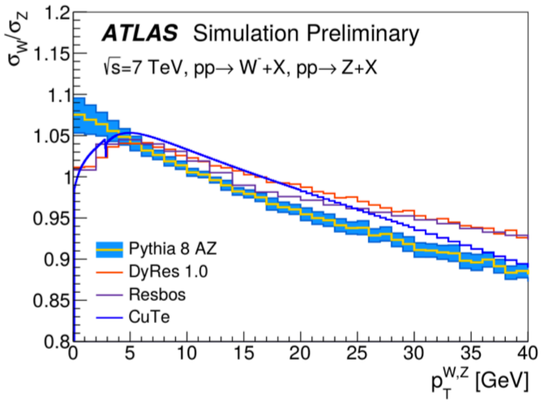


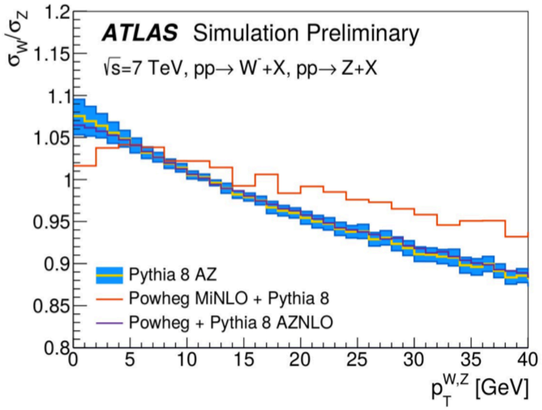
Prediction

Important aspect of this measurement

Prediction of the ratio in pT of the W and Z

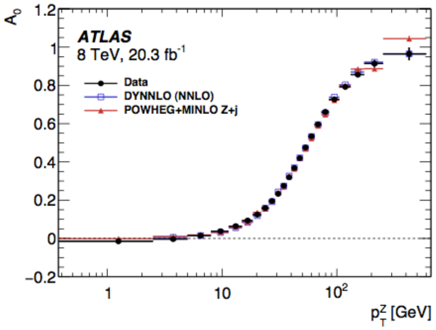


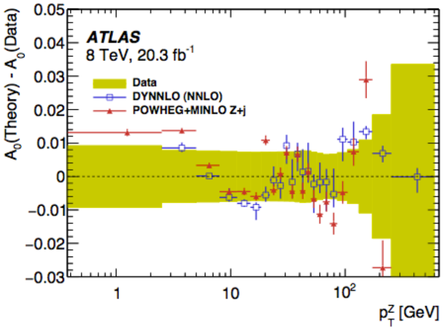


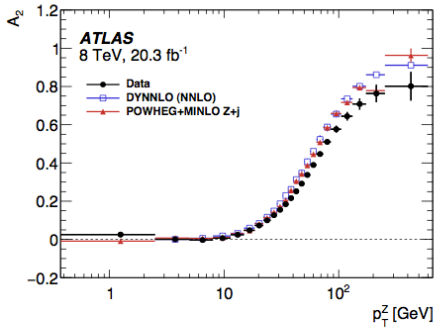


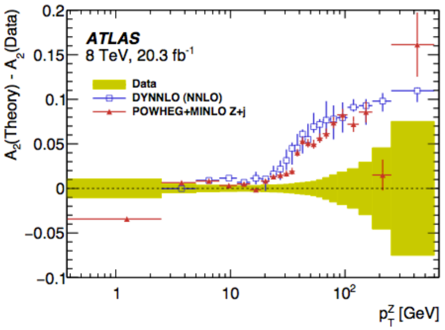
Angular coefficients in Z production (JHEP 08 (2016) 159)

Validation of the DYNNLO prediction





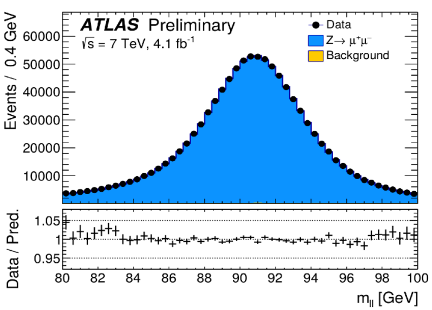


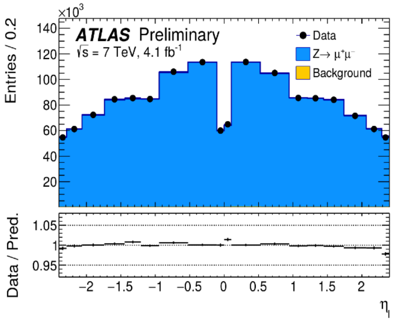


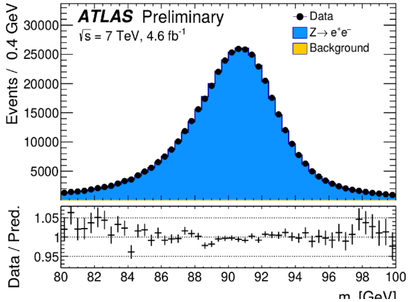
Experimental Setup

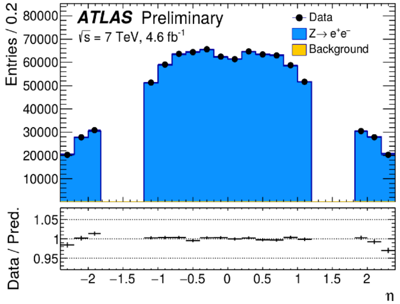
Dataset

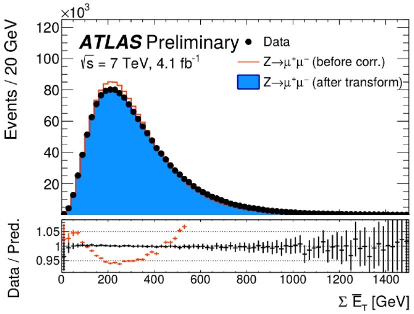
- 7 TeV only, 4.6 fb-1 (electrons) and 4.1 fb-1 (muons) well probed data at moderate PU
- Isolated electrons within pseudo-rapidity of 2.4 (electrons in the overlap region 1.2-1.8 not taken into account) with transverse momentum in excess of 30 GeV
- Kinematic cuts: MT > 60 GeV, MET > 30 GeV transverse recoil < 30 GeV

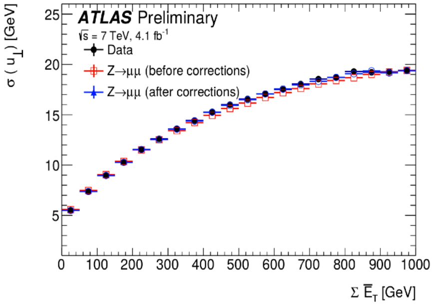


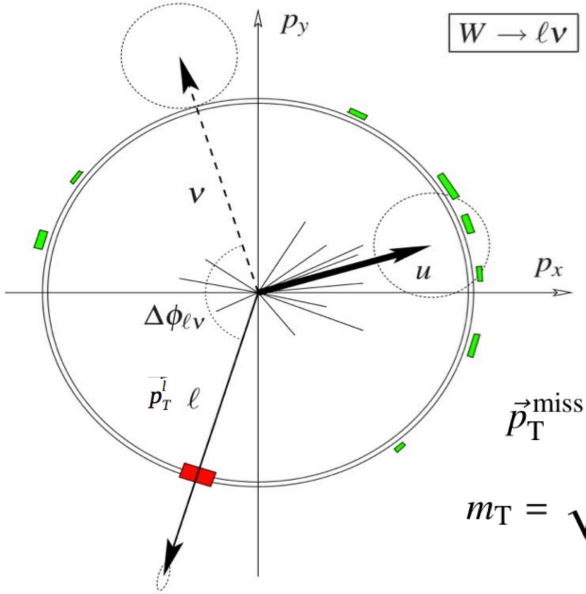








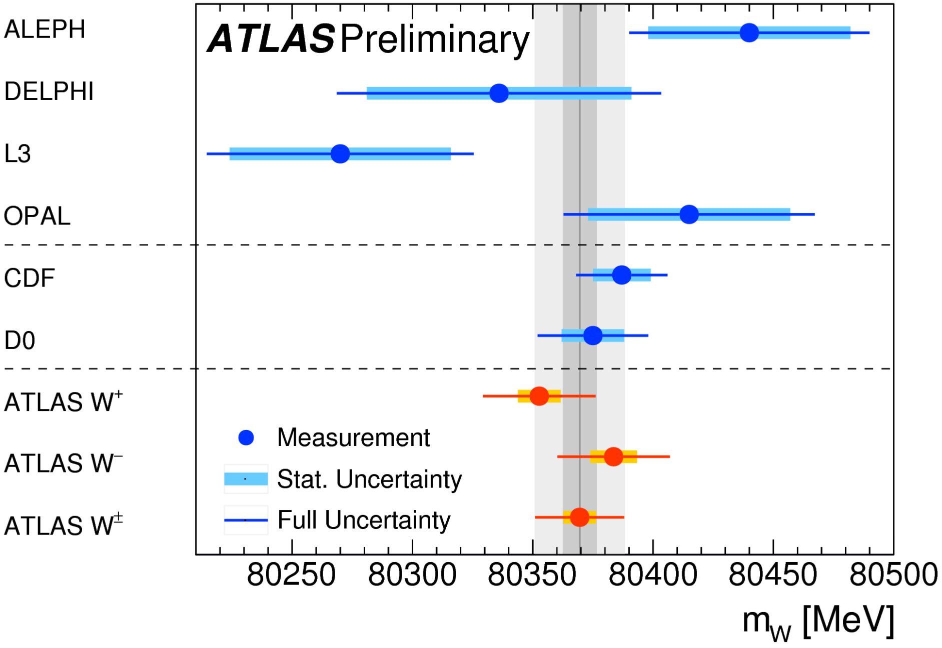




$$\vec{p}_{\mathrm{T}}^{\,\mathrm{miss}} = -\left(\vec{p}_{\mathrm{T}}^{\,\ell} + \vec{u}_{\mathrm{T}}\right)$$

$$m_{\mathrm{T}} = \sqrt{2 p_{\mathrm{T}}^{\ell} p_{\mathrm{T}}^{\mathrm{miss}} (1 - \cos \Delta\phi)}$$

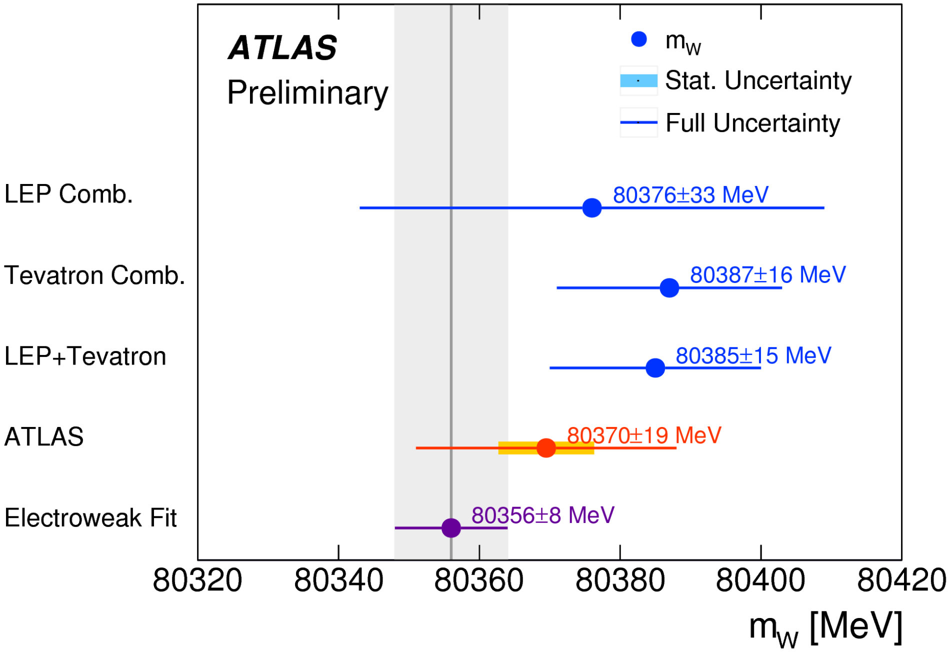
- Specific improved calibration of leptons
- Specific calibration of the recoil energy
  - First equalize PU multiplicities
  - Then correct for residual differences



$$m_W = 80369.5 \pm 18.5 MeV \\ (\pm 6.8\,(Stat) \\ \pm 10.6\,(Exp.\,Sys.) \\ \pm 13.6\,(Mod.\,Sys.)\,MeV)$$

Best individual experiment ex-aequo with CDF measurement (CDF measurement has larger statistical component 12 MeV smaller systematics – still dominated by PDFs)

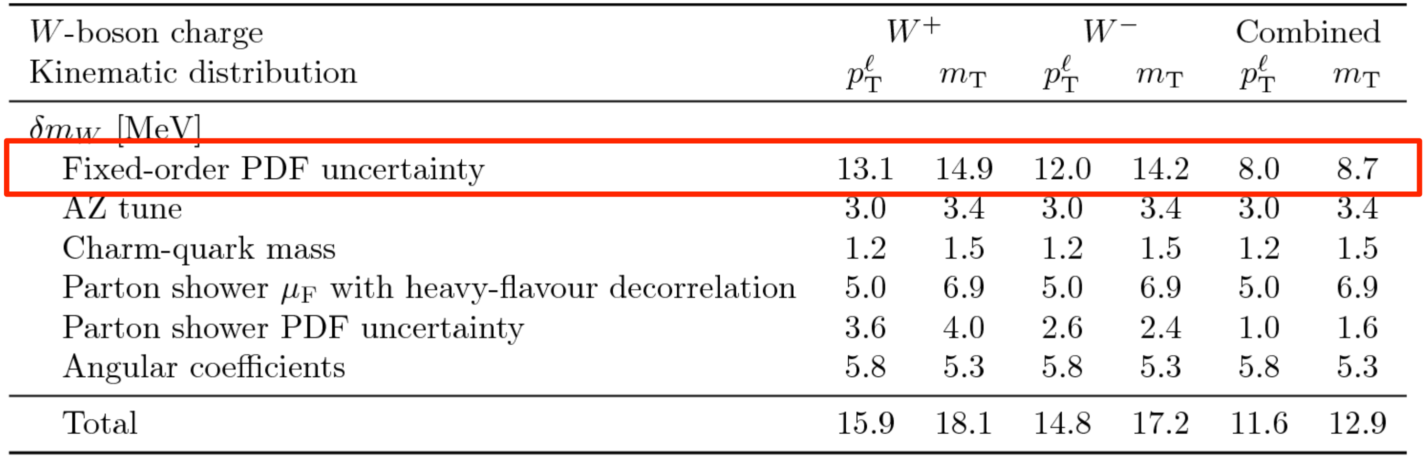
- Muon channel weighs 57% in the measurement
- The pT lepton measurement dominates weighing 86%
- Charges contribute similarly 52% vs 48%



- Modeling systematic uncertainties are largest (PDF uncertainties are dominant among modeling systematics)
- Experimental calibration systematics not negligible.

Modeling Systematic Uncertainties

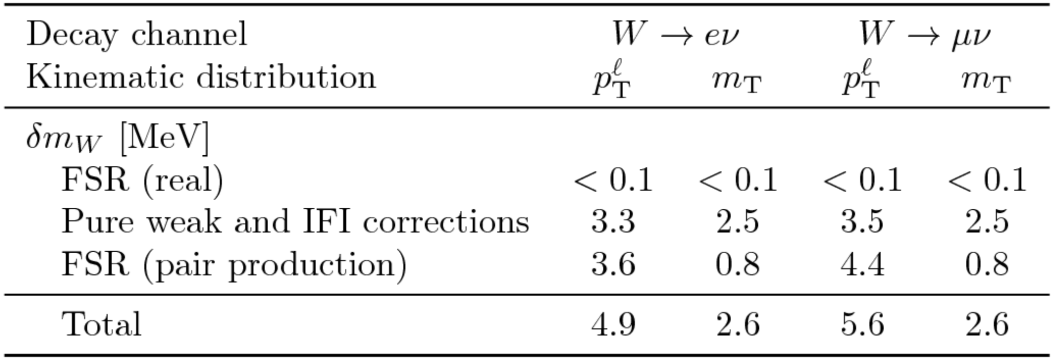
Modeling QCD



W-boson charge	W^+		W^-		Combined	
Kinematic distribution	p_T^ℓ	m_T	p_T^ℓ	m_T	p_T^ℓ	m_T
δm_W [MeV]						
Fixed-order PDF uncertainty	13.1	14.9	12.0	14.2	8.0	8.7
AZ tune	3.0	3.4	3.0	3.4	3.0	3.4
Charm-quark mass	1.2	1.5	1.2	1.5	1.2	1.5
Parton shower μ_F with heavy-flavour decorrelation	5.0	6.9	5.0	6.9	5.0	6.9
Parton shower PDF uncertainty	3.6	4.0	2.6	2.4	1.0	1.6
Angular coefficients	5.8	5.3	5.8	5.3	5.8	5.3
Total	15.9	18.1	14.8	17.2	11.6	12.9

PDF uncertainties: full CT10 variations but taking only effects affecting the W/Z ratio

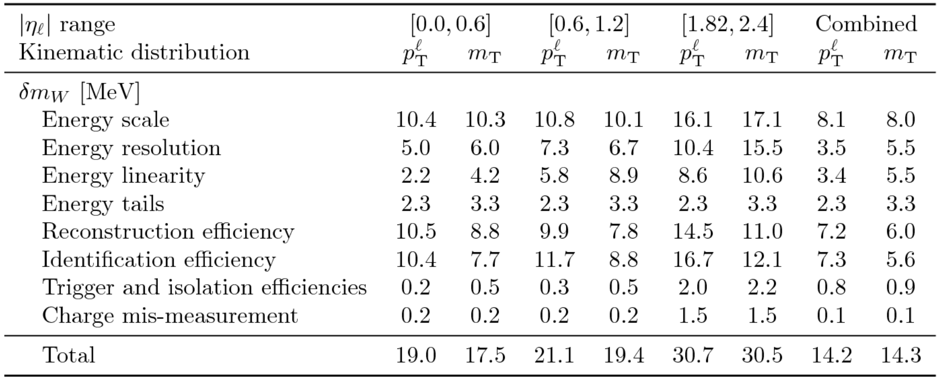
Modeling EW



Decay channel	$W \to e\nu$		$W \to \mu\nu$	
Kinematic distribution	p_T^ℓ	m_T	p_T^ℓ	m_T
δm_W [MeV]				
FSR (real)	< 0.1	< 0.1	< 0.1	< 0.1
Pure weak and IFI corrections	3.3	2.5	3.5	2.5
FSR (pair production)	3.6	0.8	4.4	0.8
Total	4.9	2.6	5.6	2.6

Experimental Systematic Uncertainties

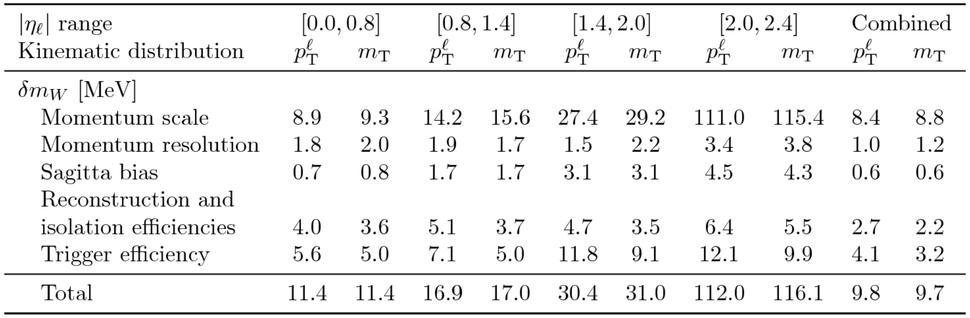
Electrons trigger, identification and calibration



$\lvert\eta_\ell\rvert$ range	[0.0, 0.6]		[0.6, 1.2]		[1.82, 2.4]		Combined	
Kinematic distribution	p_{T}^{ℓ}	m_{T}	p_{T}^{ℓ}	m_{T}	p_{T}^{ℓ}	m_{T}	p_{T}^{ℓ}	m_{T}
δm_W [MeV]								
Energy scale	10.4	10.3	10.8	10.1	16.1	17.1	8.1	8.0
Energy resolution	5.0	6.0	7.3	6.7	10.4	15.5	3.5	5.5
Energy linearity	2.2	4.2	5.8	8.9	8.6	10.6	3.4	5.5
Energy tails	2.3	3.3	2.3	3.3	2.3	3.3	2.3	3.3
Reconstruction efficiency	10.5	8.8	9.9	7.8	14.5	11.0	7.2	6.0
Identification efficiency	10.4	7.7	11.7	8.8	16.7	12.1	7.3	5.6
Trigger and isolation efficiencies	0.2	0.5	0.3	0.5	2.0	2.2	0.8	0.9
Charge mis-measurement	0.2	0.2	0.2	0.2	1.5	1.5	0.1	0.1
Total	19.0	17.5	21.1	19.4	30.7	30.5	14.2	14.3

- Uncertainties dominated by energy scale, and reconstruction and identification efficiencies
- Of course correlated between pT and mT

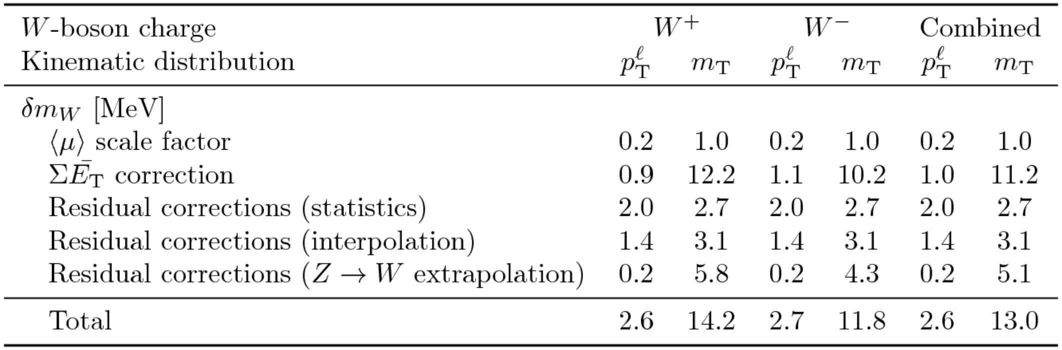
Muons trigger, identification and calibration



$\lvert\eta_\ell\rvert$ range	[0.0, 0.8]		[0.8, 1.4]		[1.4, 2.0]		[2.0, 2.4]		Combined	
Kinematic distribution	p_{T}^{ℓ}	m_{T}	p_{T}^{ℓ}	m_{T}	p_{T}^{ℓ}	m_{T}	p_{T}^{ℓ}	m_{T}	p_{T}^{ℓ}	m_{T}
δm_W [MeV]										
Momentum scale	8.9	9.3	14.2	15.6	27.4	29.2	111.0	115.4	8.4	8.8
Momentum resolution	1.8	2.0	1.9	1.7	1.5	2.2	3.4	3.8	1.0	1.2
Sagitta bias	0.7	0.8	1.7	1.7	3.1	3.1	4.5	4.3	0.6	0.6
Reconstruction and isolation efficiencies	4.0	3.6	5.1	3.7	4.7	3.5	6.4	5.5	2.7	2.2
Trigger efficiency	5.6	5.0	7.1	5.0	11.8	9.1	12.1	9.9	4.1	3.2
Total	11.4	11.4	16.9	17.0	30.4	31.0	112.0	116.1	9.8	9.7

- Uncertainties dominated by momentum scales
- Of course correlated between pT and mT

Recoil

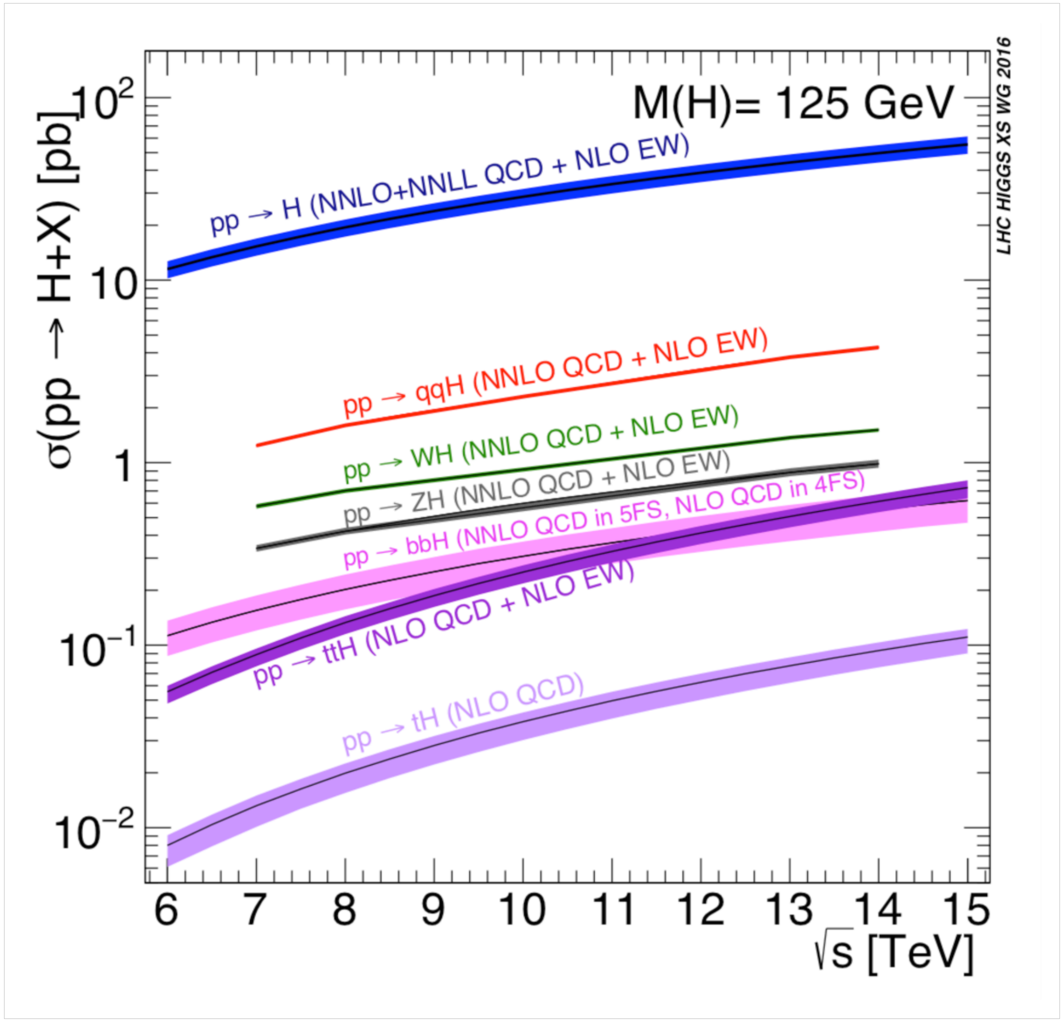


W-boson charge	W^+		W^-		Combined	
Kinematic distribution	p_{T}^{ℓ}	m_{T}	p_{T}^{ℓ}	m_{T}	p_{T}^{ℓ}	m_{T}
δm_W [MeV]						
$\langle\mu\rangle$ scale factor	0.2	1.0	0.2	1.0	0.2	1.0
$\Sigma\bar{E}_{\mathrm{T}}$ correction	0.9	12.2	1.1	10.2	1.0	11.2
Residual corrections (statistics)	2.0	2.7	2.0	2.7	2.0	2.7
Residual corrections (interpolation)	1.4	3.1	1.4	3.1	1.4	3.1
Residual corrections ($Z \to W$ extrapolation)	0.2	5.8	0.2	4.3	0.2	5.1
Total	2.6	14.2	2.7	11.8	2.6	13.0

- Dominated by the recoil correction (Z statistics)
- Of course affecting only mT measurement

Run 2 Higgs Results

Nano summary



Increase in production cross section from 7 TeV to 13 TeV

ggH ~ 2.3

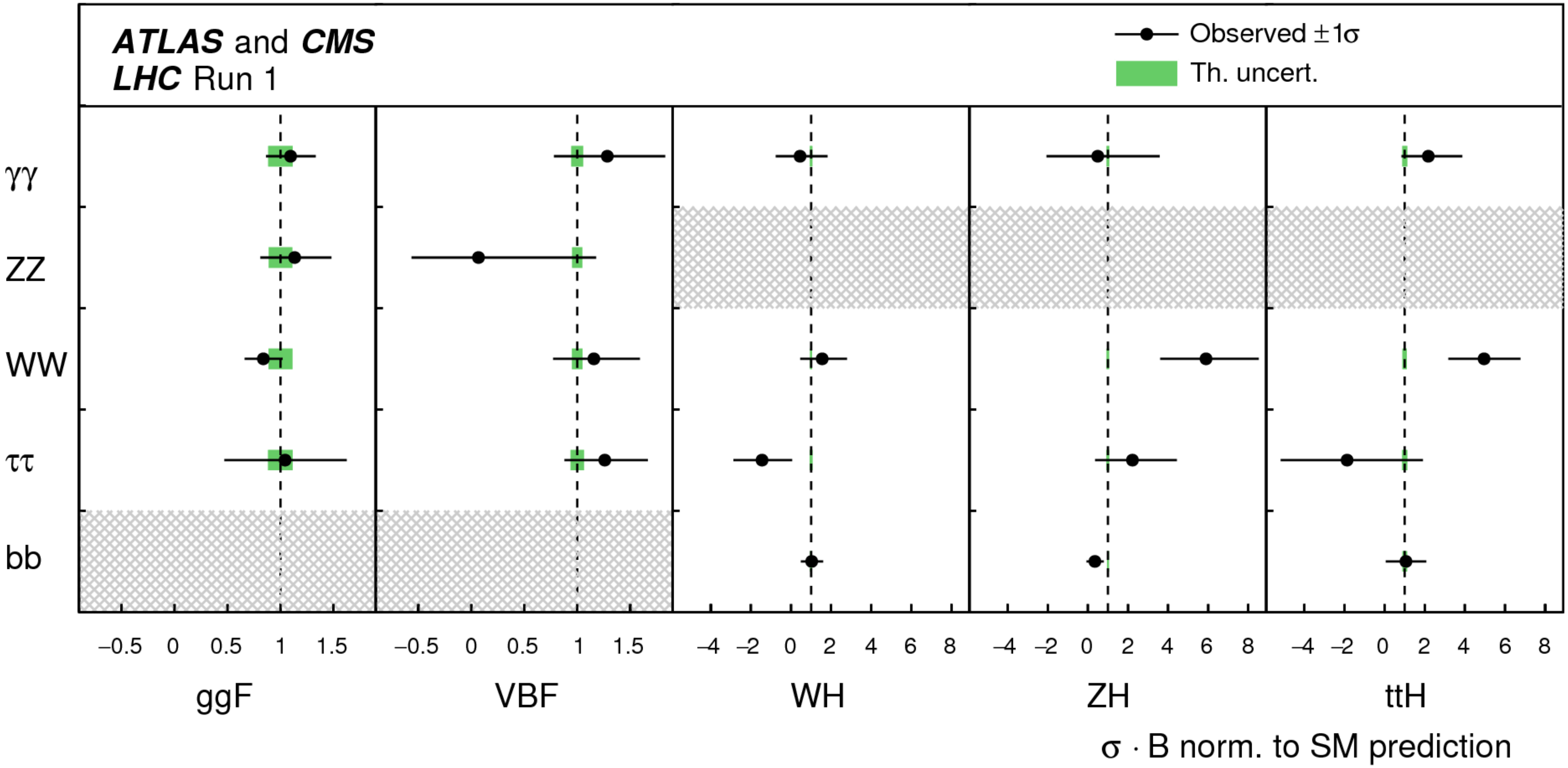
VBF ~ 2.4

VH ~ 2.9

ttH ~ 3.9

Run 1 Status of the Higgs Couplings Measurements

(Simplified or combined*) panorama of higgs channels used (many more categories are used in each case and two experiments)

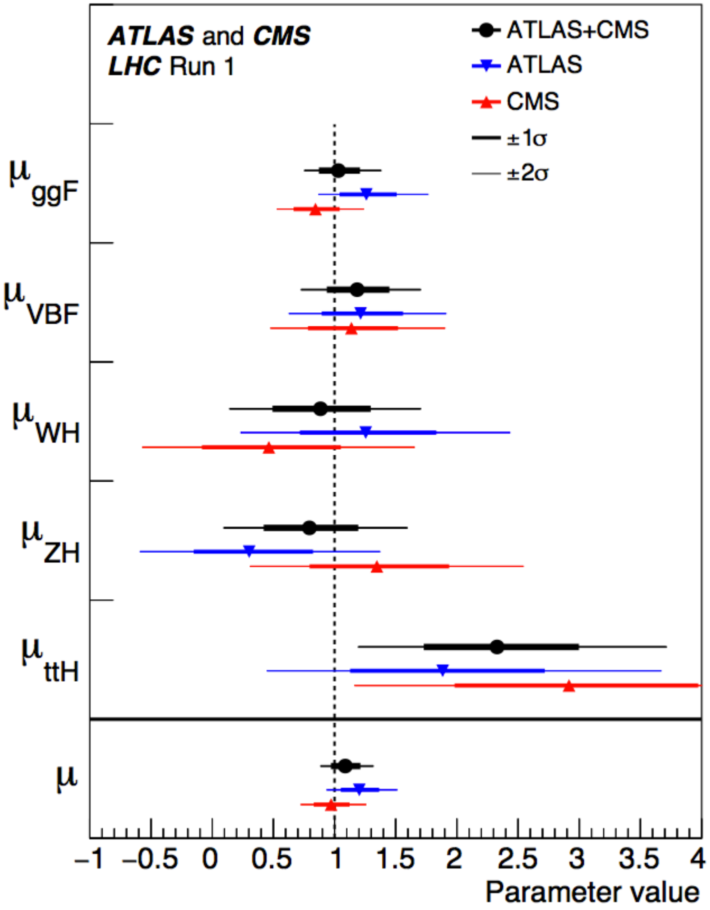


JHEP 08 (2016) 045

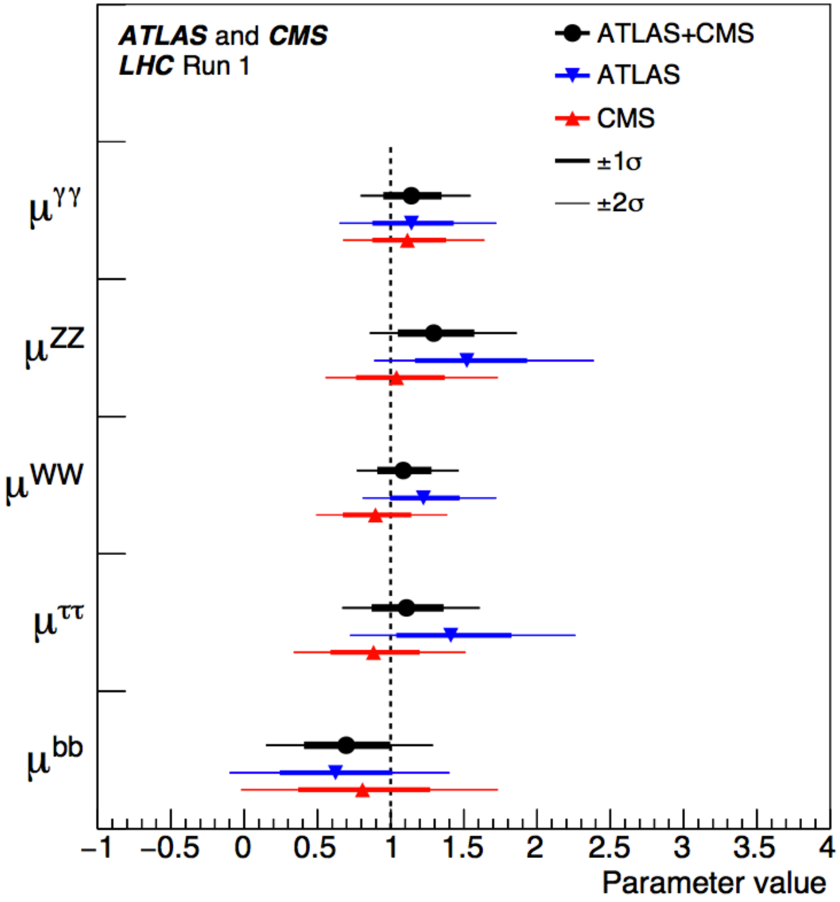
*Combination assumes narrow width approximation

Cross Sections and Branching Ratios

Combined Measurements
assuming SM branchings



Combined Measurements
assuming SM Cross Sections

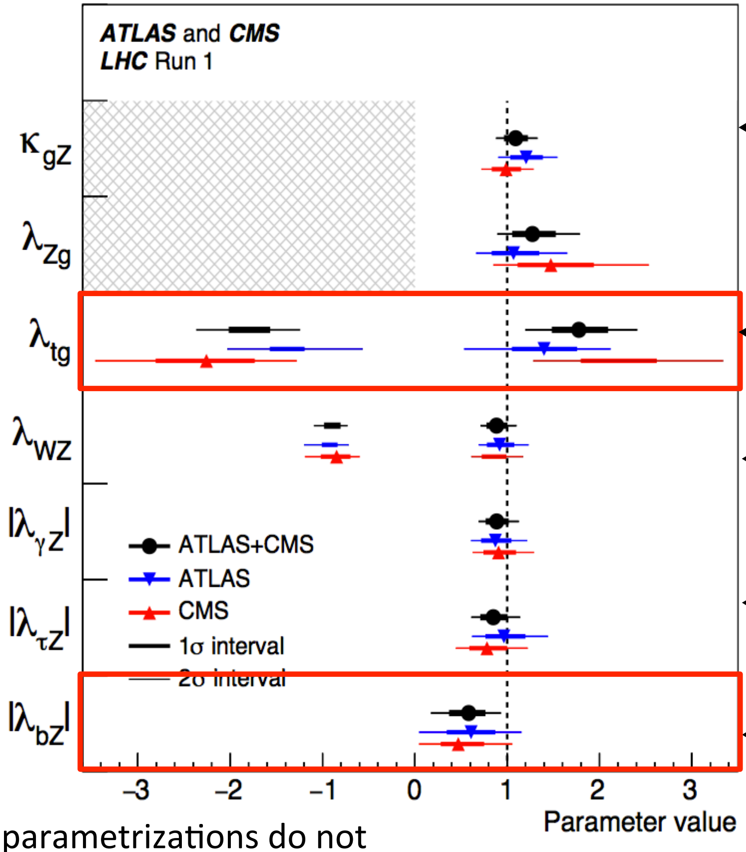


Run 1 Status of the Higgs Couplings Measurements

$$\mu = 1.09 \quad \pm 0.11 \; (\pm 0.07\,(Stat) \; \pm 0.04\,(Exp) \; \pm 0.03\,(Th.\,bkg) \; \pm 0.07\,(Th.\,sig)\,)$$

Signal strength illustrates the agreement of measurements with the SM and the importance of the TH input.

Very illustrative, but not transparent on the underlying assumptions and relies on the TH input at a given time.



Δκ/κ ~ 11%

Δλ/λ ~ 23%

Δλ/λ ~ 30%

Δλ/λ ~ 11%

Δλ/λ ~ 12%

Δλ/λ ~ 16%

Δλ/λ ~ 34%

Direct coupling to the Z

Direct coupling to the top*
(through ttH production channels)

Custodial Symmetry

Direct copling to τ
(through VBF production)

Direct coupling to b quarks*
(Through mainly VH channels)

*κ and λ framework parametrizations do not take into account the higher order.

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A few comments on the next steps in precision

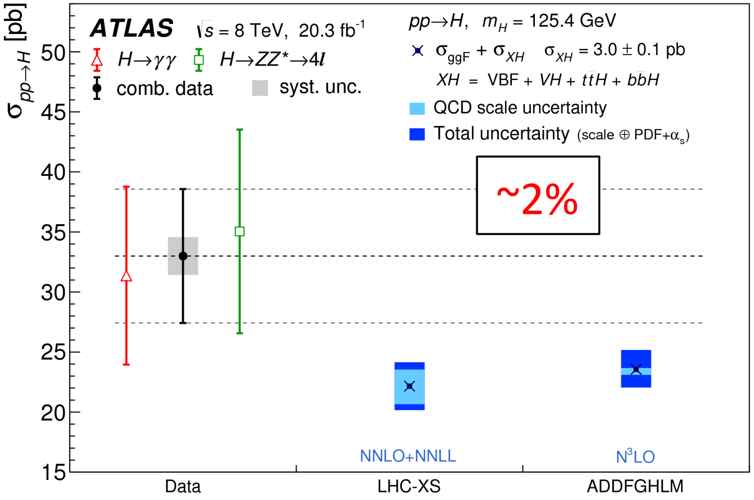
$$\begin{aligned} \mu = 1.09 \quad & \pm 0.11 \\ & (\pm 0.07\,(Stat) \\ & \ \pm 0.04\,(Exp) \\ & \ \pm 0.03\,(Th.\,bkg) \\ & \ \pm 0.07\,(Th.\,sig)\ ) \end{aligned}$$

See Run 2: typically x2 in cross section (x4 for ttH) and much much more data (and more PU).

Most Exp. Uncertainties are estimated from the data, and should also reduced with more statistics (of course real life case will be more complicated – again e.g. PU).

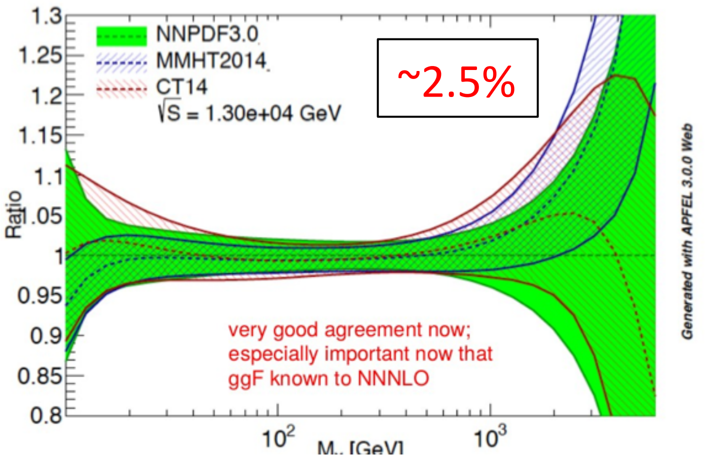
See next slide.

Breakthrough!



~2%

Important convergence



~2.5%

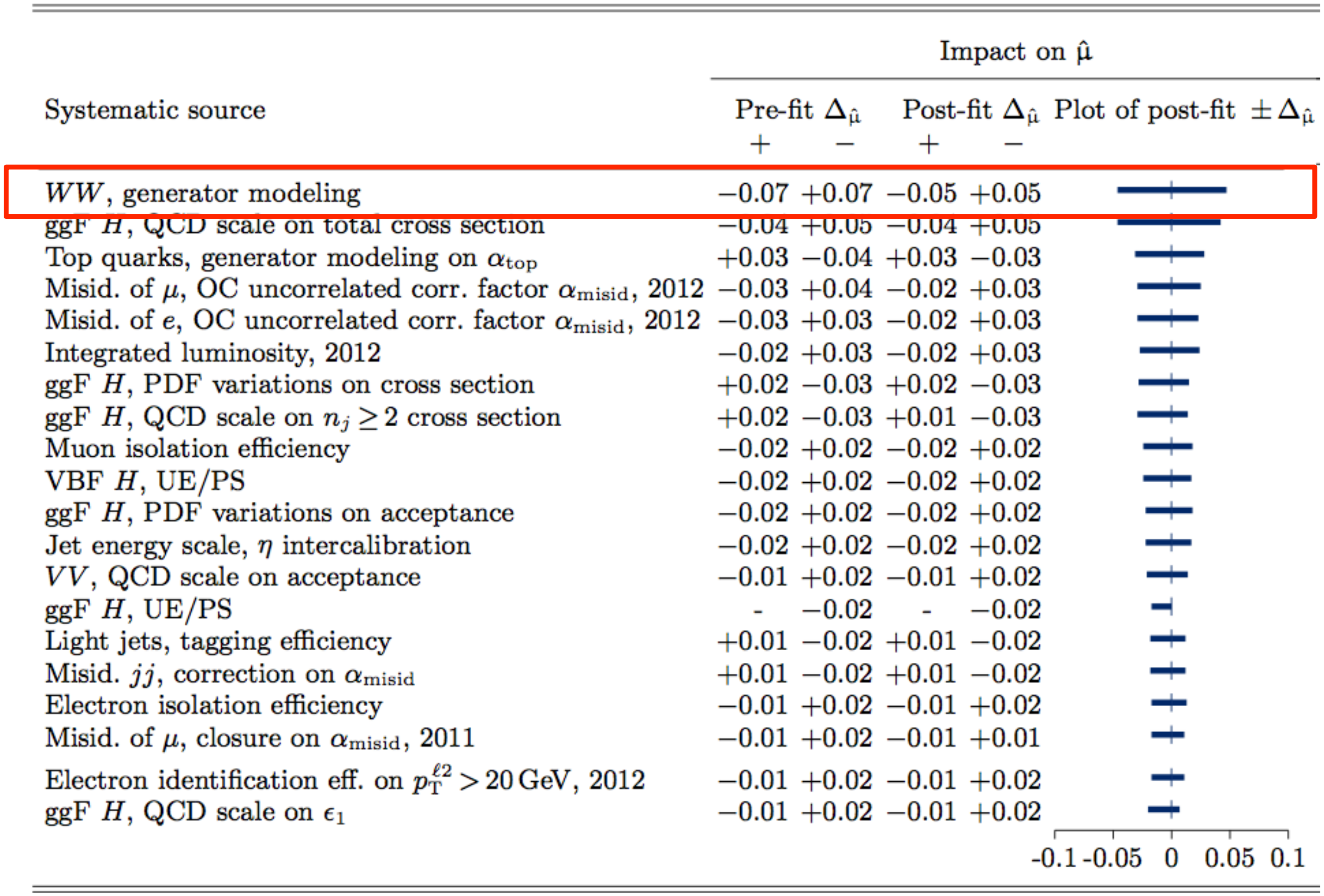
See talk by Joey Huston

Uncertainty on α_s will require attention: probably underestimated currently.

~1.5%

Background systematic uncertainties

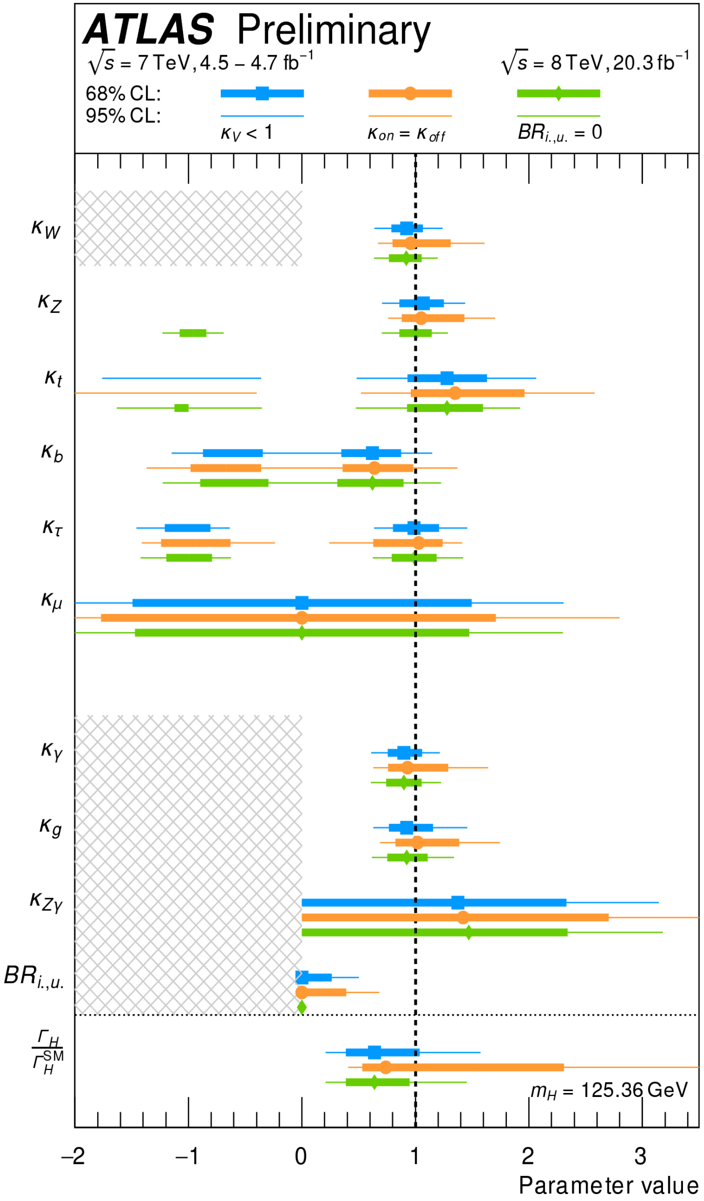
The WW channel



Systematic source	Impact on $\hat{\mu}$ Pre-fit $\Delta_{\hat{\mu}}$ +	Pre-fit $\Delta_{\hat{\mu}}$ −	Post-fit $\Delta_{\hat{\mu}}$ +	Post-fit $\Delta_{\hat{\mu}}$ −	Plot of post-fit $\pm\Delta_{\hat{\mu}}$
WW, generator modeling	−0.07	+0.07	−0.05	+0.05	
ggF H, QCD scale on total cross section	−0.04	+0.05	−0.04	+0.05	
Top quarks, generator modeling on α_{top}	+0.03	−0.04	+0.03	−0.03	
Misid. of μ, OC uncorrelated corr. factor α_{misid}, 2012	−0.03	+0.04	−0.02	+0.03	
Misid. of e, OC uncorrelated corr. factor α_{misid}, 2012	−0.03	+0.03	−0.02	+0.03	
Integrated luminosity, 2012	−0.02	+0.03	−0.02	+0.03	
ggF H, PDF variations on cross section	+0.02	−0.03	+0.02	−0.03	
ggF H, QCD scale on $n_j \geq 2$ cross section	+0.02	−0.03	+0.01	−0.03	
Muon isolation efficiency	−0.02	+0.02	−0.02	+0.02	
VBF H, UE/PS	−0.02	+0.02	−0.02	+0.02	
ggF H, PDF variations on acceptance	−0.02	+0.02	−0.02	+0.02	
Jet energy scale, η intercalibration	−0.02	+0.02	−0.02	+0.02	
VV, QCD scale on acceptance	−0.01	+0.02	−0.01	+0.02	
ggF H, UE/PS	-	−0.02	-	−0.02	
Light jets, tagging efficiency	+0.01	−0.02	+0.01	−0.02	
Misid. jj, correction on α_{misid}	+0.01	−0.02	+0.01	−0.02	
Electron isolation efficiency	−0.01	+0.02	−0.01	+0.02	
Misid. of μ, closure on α_{misid}, 2011	−0.01	+0.02	−0.01	+0.01	
Electron identification eff. on $p_{\mathrm{T}}^{\ell 2} > 20\,\mathrm{GeV}$, 2012	−0.01	+0.02	−0.01	+0.02	
ggF H, QCD scale on ϵ_1	−0.01	+0.02	−0.01	+0.02	

Important addition: NNLO fiducial available but not used yet!

Comments on the Absolute Measurement of Couplings



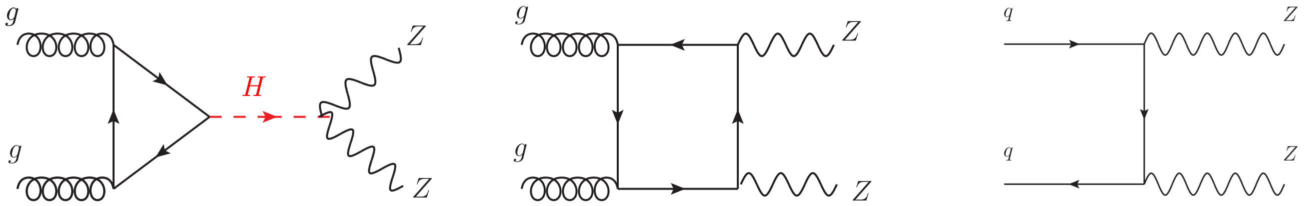
Absolute couplings measurements under specific conditions:

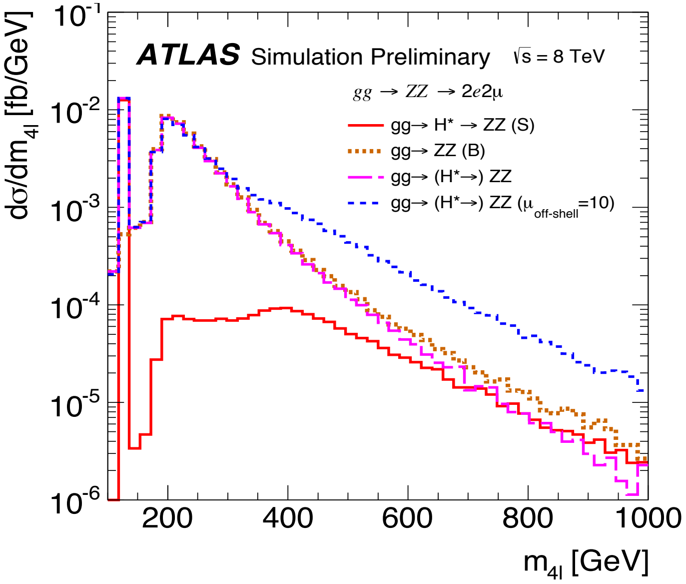
- **Green**: Constrain the width to SM field content only.
- **Blue**: Unitarity inspired constraint $k_V < 1$
- **Orange**: Use measurement from Off-Shell coupling*

*Requires constraint of equal OffShell and OnShell Higgs couplings

Comments on Off Shell Higgs

Study the Higgs boson as a propagator





Preliminary HL-LHC results show that a reasonable sensitivity can be obtained with 3 ab-1:

$$\Gamma_H = 4.2^{+1.5}_{-2.1}\, MeV$$

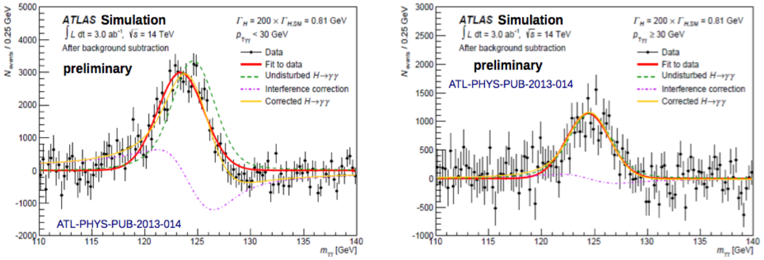
ATL-PHYS-PUB-2015-024

Results obtained at Run 1 are already impressive (experimental limits at 30 MeV per experiment level on total width of the Higgs boson) and have highlighted interesting points in the interplay between diboson and Higgs Off shell:

- Importance of gg to VV at NLO
- Importance of the qq to VV background and EW coretions
- How to best estimate/parametrize error on interference

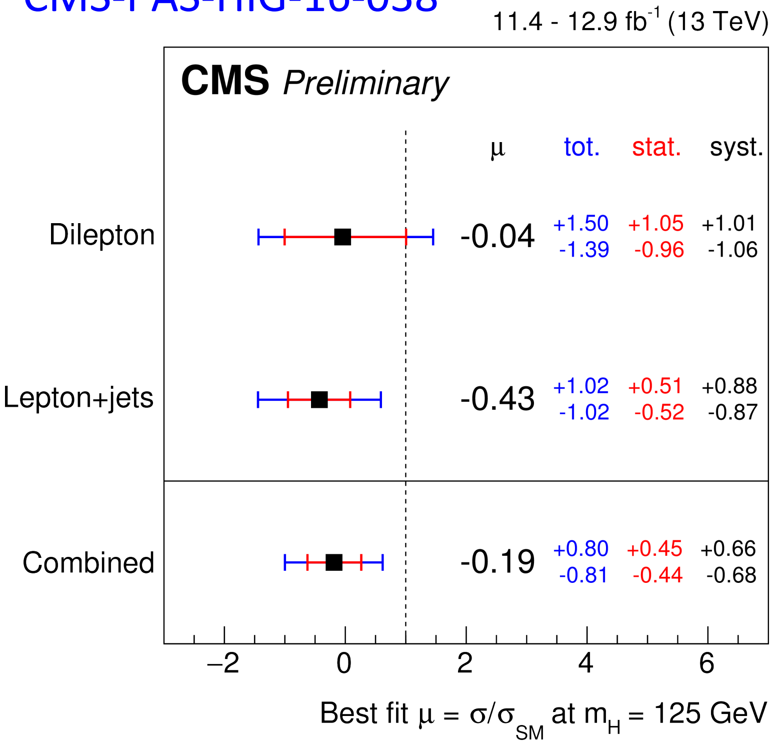
ATL-PHYS-PUB-2013-014

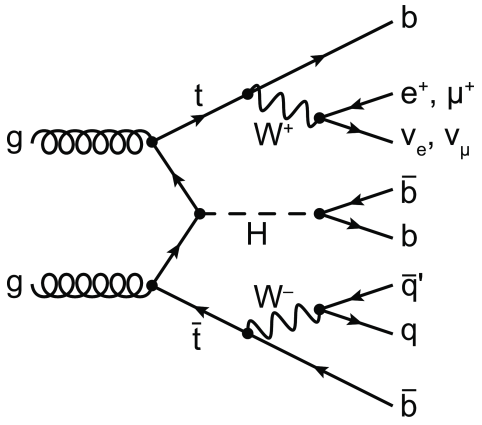
In comparison limit from mass shift in diphoton channel is ~200 for 3 ab^{-1}



Highly Anticipated Higgs Analyses at Run 2 (I)

CMS-PAS-HIG-16-038





ttH Recent updateon the (bb) decay mode, completing the picture with the ICHEP dataset.

Analysis relying mostly on top modeling in very difficult regions e.g. 1L-6J-4b!

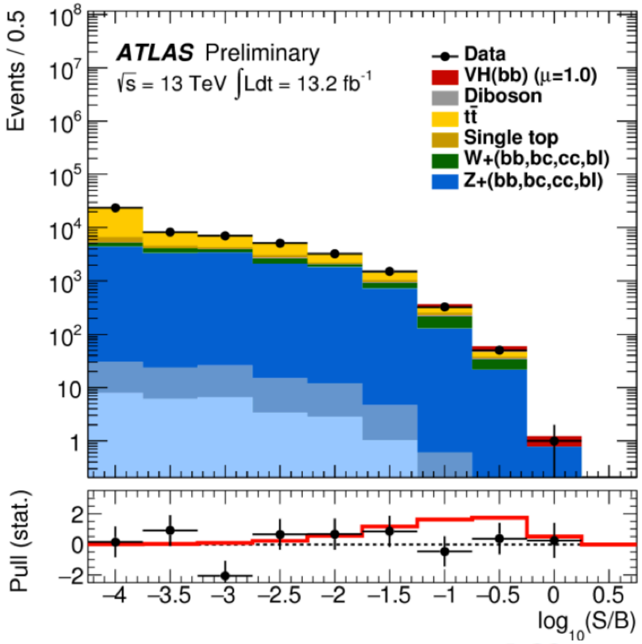
	γγ	bb	ML	Comb.
ATLAS Run 1	1.2 ± 2.6	1.4 ± 0.6 (stat) ± 0.8 (syst)	2.1 ± 1.1 (stat) ± 0.9 (syst)	1.7 ± 0.8
CMS Run 1	2.7 ± 2.6	0.7 ± 1.9	3.3 ± 1.4	2.8 ± 0.9
ATLAS Run 2	-0.3 ± 1.2	2.1 ± 0.5 (stat) ± 0.9 (syst)	2.5 ± 0.7 (stat) ± 1.1 (syst)	1.8 ± 0.7
CMS Run 2	$1.9^{+1.5}_{-1.2}$	-0.19 ± 0.8	$2.4^{+1.3}_{-1.2}$	0.8 ± 0.6

0.9 ± 0.8 Diphoton only BE comb.

1.58 ± 0.36 approx. 1.6σ high

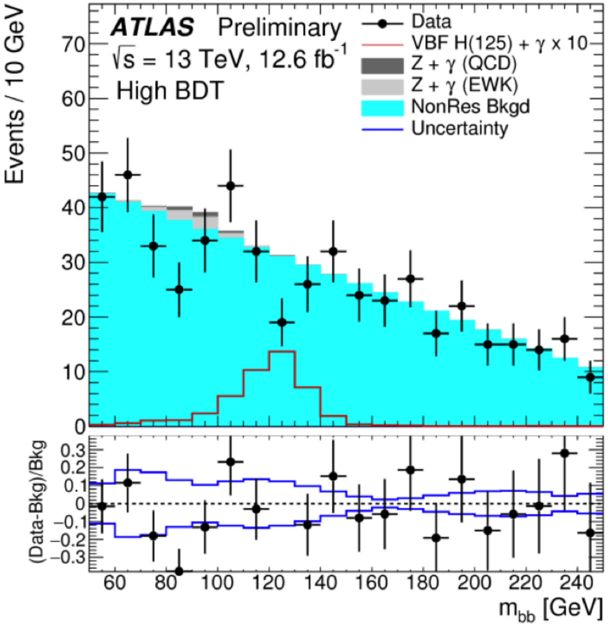
Highly Anticipated Higgs Analyses at Run 2 (II)

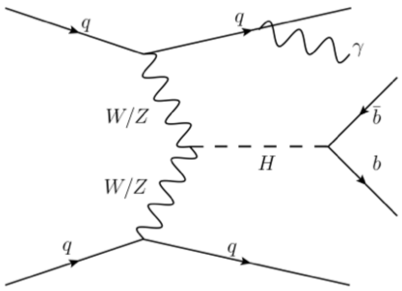
ATLAS-CONF-2016-091



$$\mu_{VZ} = 0.91 \pm 0.17(\text{stat.})^{+0.32}_{-0.27}(\text{syst.})$$

ATLAS-CONF-2016-067

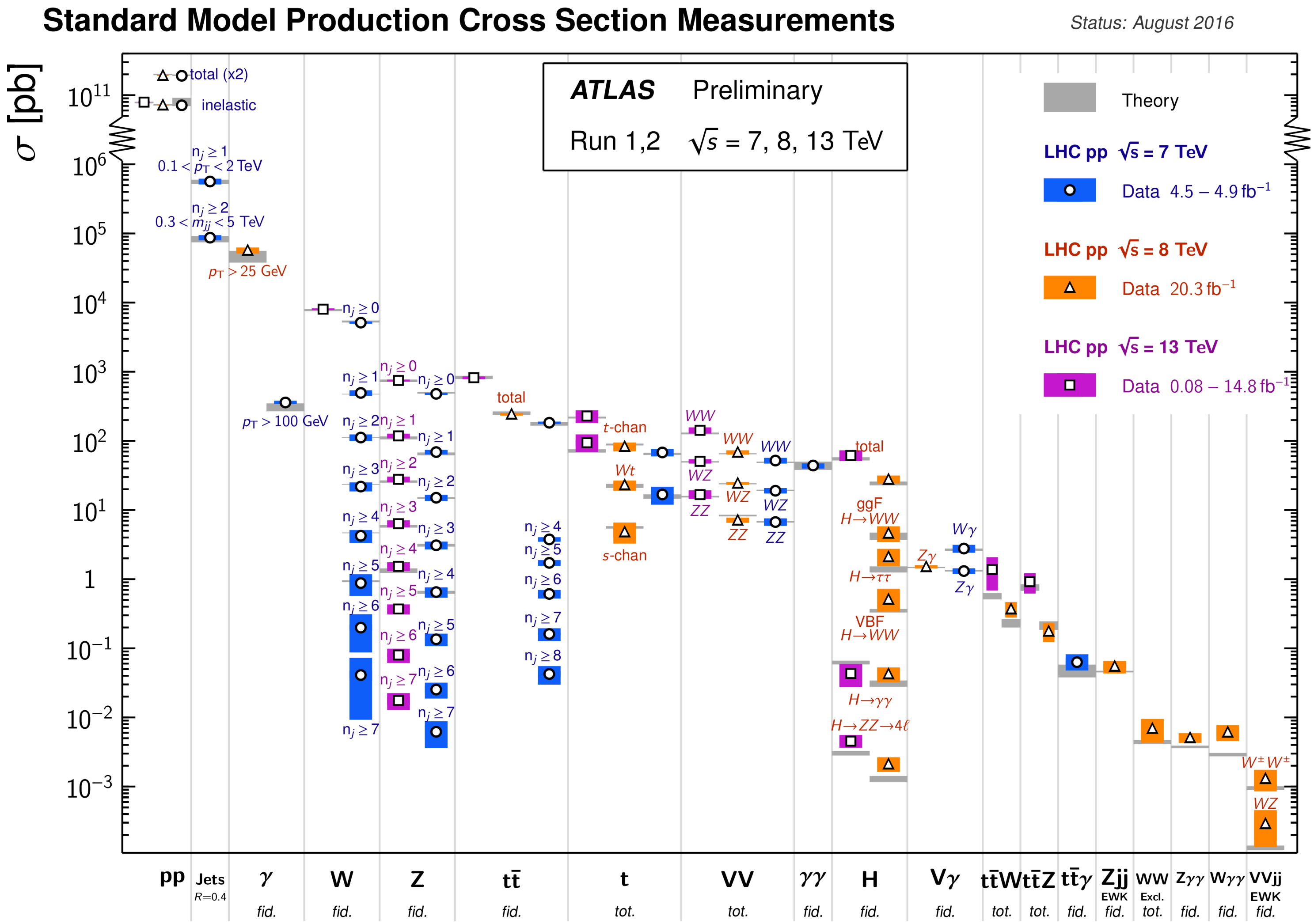




	VH	ttH	VBF
ATLAS Run 1	0.52 ± 0.32 (stat) ± 0.24 (syst)	1.4 ± 0.6 (stat) ± 0.8 (syst)	-
CMS Run 1	1.0 ± 0.5	0.7 ± 1.9	2.8 ± 1.4
ATLAS Run 2	0.21 ± 0.36 (stat) ± 0.36 (syst)	2.1 ± 0.5 (stat) ± 0.9 (syst)	-3.9 ± 2.8
CMS Run 2	-	-0.19 ± 0.5 (stat) ± 0.7 (syst)	-3.7 ± 2.7

Back-of-the-enveloppe combination: 0.64 ± 0.23 (0.56 ± 0.27 vor VH only) approx. 1.6σ low

Precision QCD Measurements at LHC



Excellent agreement of all cross section measurements with the SM prediction

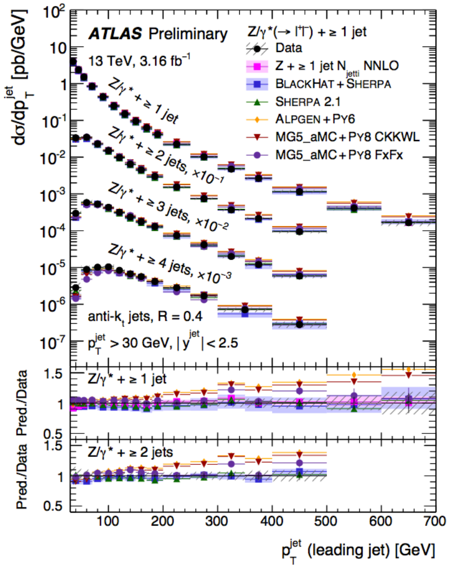
Remarkable recent progress:

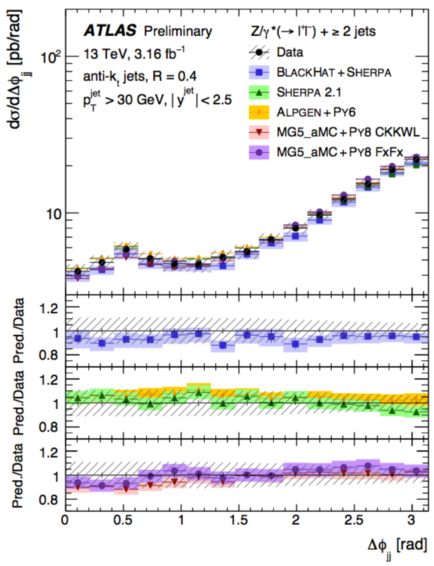
- in MC (in number of loops and legs)
- In Fixed order/resummed calculation
- Constant improvements in PDFs

Also extremely important past progress, e.g. fast jet alg. Allowing for IR and col. Safe jet algorithms at LHC

Modeling is Critical

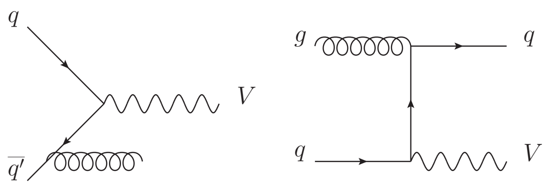
At Run 2: huge effort to use (and therefore validate) State-of-the-Art MC.





V+jets production

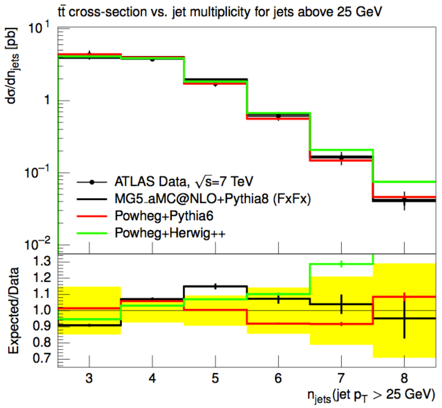
Crucial in the VH(bb) analysis and many more

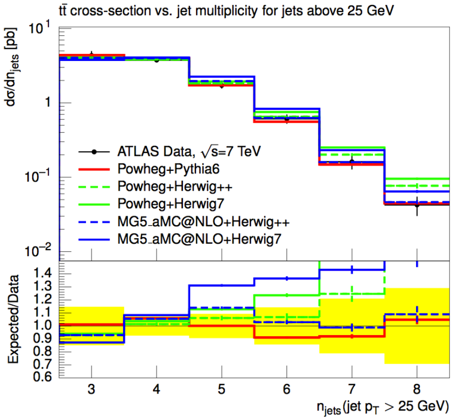


Already improvements w.r.t. to Run 1 and for the full dataset considering Sherpa 2.2.

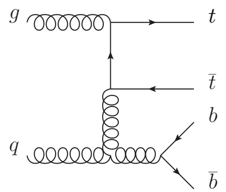
This illustrates the very fast turn around to include latest MC developments.

Top(+jets) production





Crucial in the ttH(bb) analysis and many more



Crucial role played by HEPData

(and Rivet routines)

Flavor Physics Anomalies

~ 3.5σ	Muon anomalous mag. Moment g-2 anomaly - BNL E821
~ 3.5σ	di-muon like-sign charge asymmetry (D0)
~ 3.5σ	Enahnced B to $D^*\tau\nu$ - BaBar also Belle and LHCb
~ 3.5σ	B to $\phi\mu\mu$ branching deficit in low q^2 (1-6 GeV^2) – LHCb
~ 3σ	Inclusive vs. Exclusive $\|V_{ub}\|$
~ 3σ	Inclusive vs. Exclusive $\|V_{cb}\|$
~ $2\text{-}3\sigma$	B to $K^*\mu\mu$ angular – LHCb and Belle
~ $2\text{-}3\sigma$	ε'/ε SM prediction below measurment
~ 2.5σ	R_K (B to $K\mu\mu$ /B to Kee)
~ 2σ	Higgs to $\tau\mu$ – CMS and ATLAS

Large number of modest tensions! More interesting data soon…

Conclusion of Measurements at the LHC

Experimental triumph of the Standard Model within current precision, but not fully satisfactory from the TH…

However there are still important guidelines

- Two of the three main Naturalness problems (the other one is CC):
  - Hierarchy
  - Strong CP
- Nature of Dark Matter
- Flavor hierarchy (and neutrino masses)
- Matter-anti-matter asymmetry
- Grand Unification

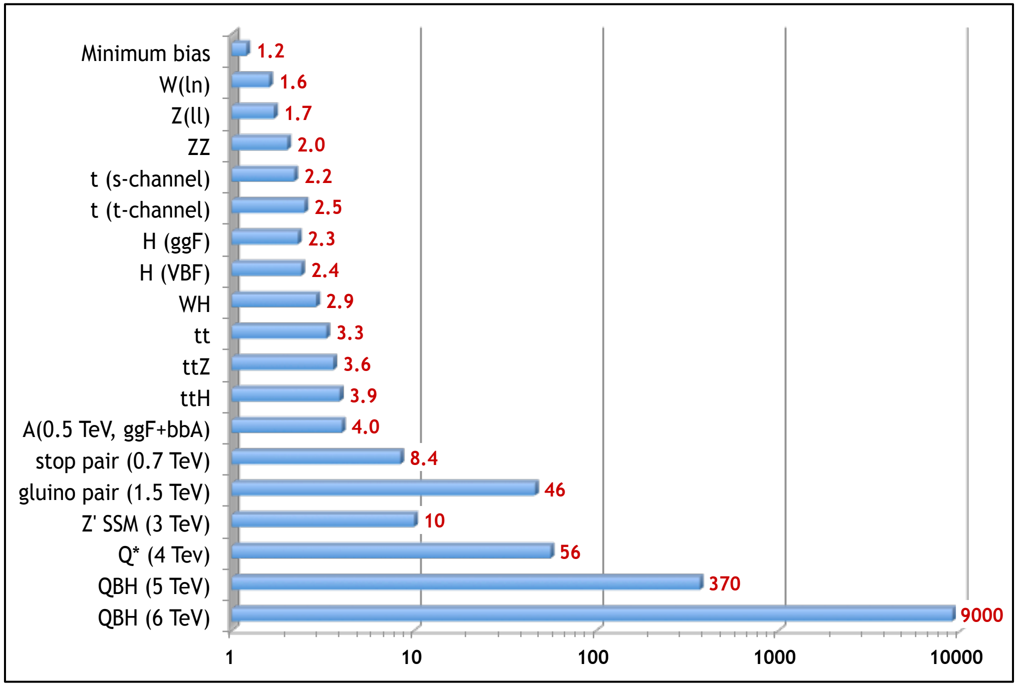
These guidelines are essential in our strategy for searches in the absence of a "No loose theorem"…

See John Paul’s talk

Direct Searches at LHC

The LHC is a discovery machine: Both at the Energy and the luminosity frontiers.

Ratio of parton luminosities



The **increase of centre-of-mass energy** at Run 2 has brought the potential for spectacular (prompt) discoveries 2015 and 2016 have been extremely exciting because

2015 -2016: **Discovery mode**, with a rapid doubling time of the luminosity.

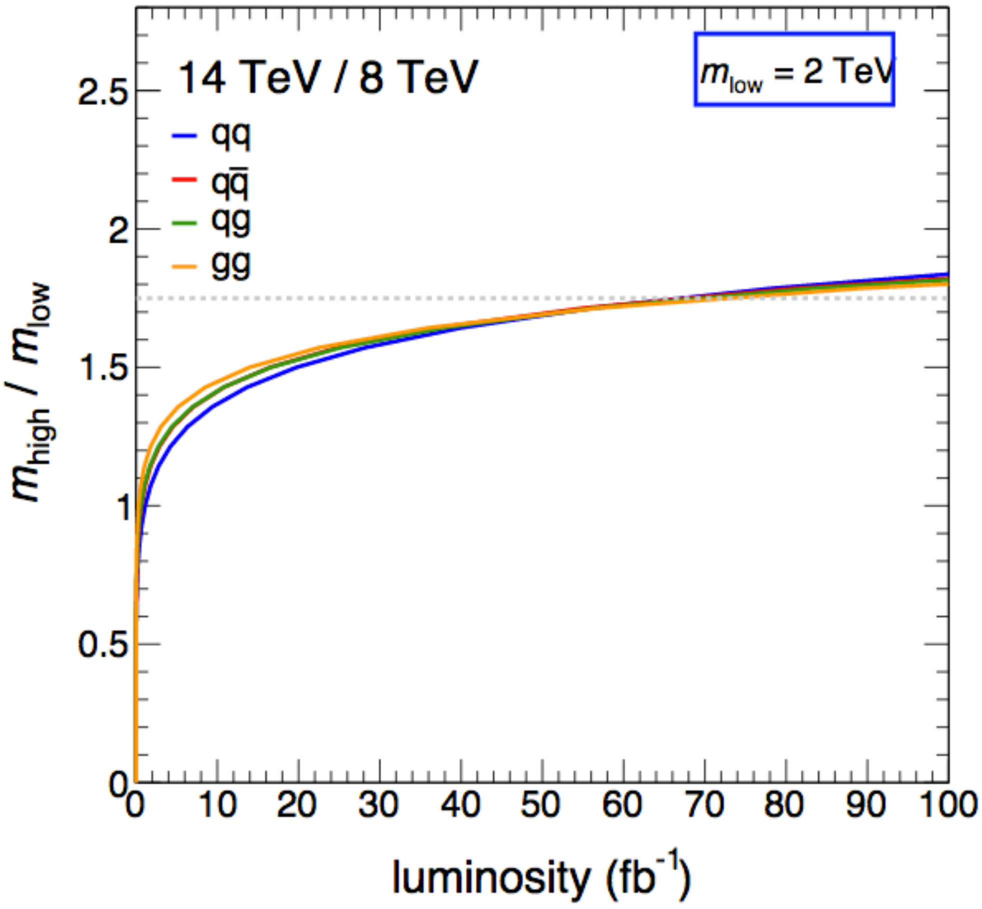
Able to verify rapidly if any effect is a statistical fluctuation.

Strategy:

- Search exhaustively all possible relevant topologies where new physics scenarios can occur according. Leave no stone unturned.
- **Interaction with new TH/PH ideas is very important!**
- Keep track of possible excesses (Run 1 and 2015 data), and verify them with an independent sample.

A word about Luminosity

Run 1 limit 2 TeV, e.g. pair of 1 TeV gluino.



Entering a new phase of searches, where a discovery will still be possible but will take time.

High Mass and Transverse Momentum

Modes for discovery at LHC

Search for narrow or less narrow peaks
(Depending on the underlying dynamics)

- W’ and Z’ (Extra dimensions)
- Additional Higgs bosons
- Excited quarks q^*
- Leptoquarks
- RS gravitons
- String resonances
- E6 diquarks
- Axi gluons

Non resonant searches

- ADD gravitons
- Quantum black holes
- Contact interactions

Topologies: Two photons, two jets, photon-jet, lepton-photon, lepton-jet, top pair, Z-photon, VV, VH, HH

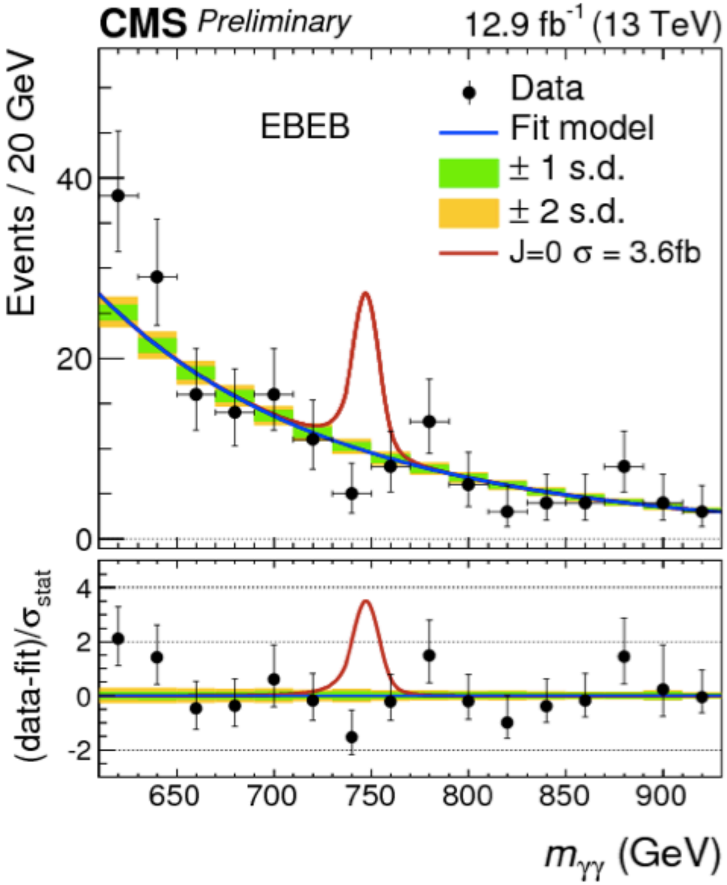
Diphoton Search

The 750 GeV Excess

* Definitely most interesting + likely LHC anomaly - Exciting!

[* Run 1 vs Ru2 tension, "other channels look elsewhere", width issue; also big co-incidence that $S/B \sim$ few with $\mathcal{O}(10)$ events (but just where syst/background fluct. hurt!)]

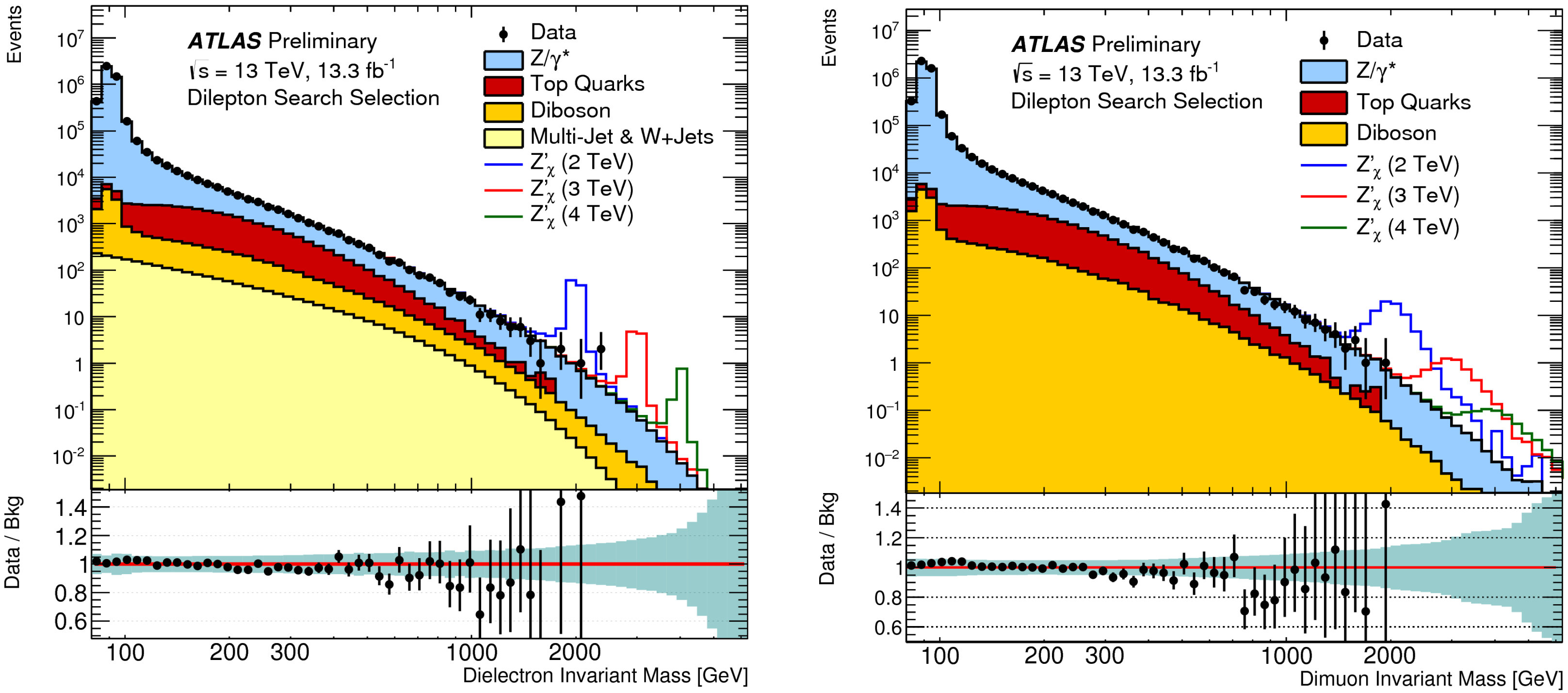
* I give it a ~ 10% chance of being real (= betting odds)



Nima Arkani Hamed (Aspen 2016)

Search for High Mass Z’

ATLAS-CONF-2016-045



- Understanding extrapolation of the calibration and the reconstruction efficiency at very high transverse momentum is critical.

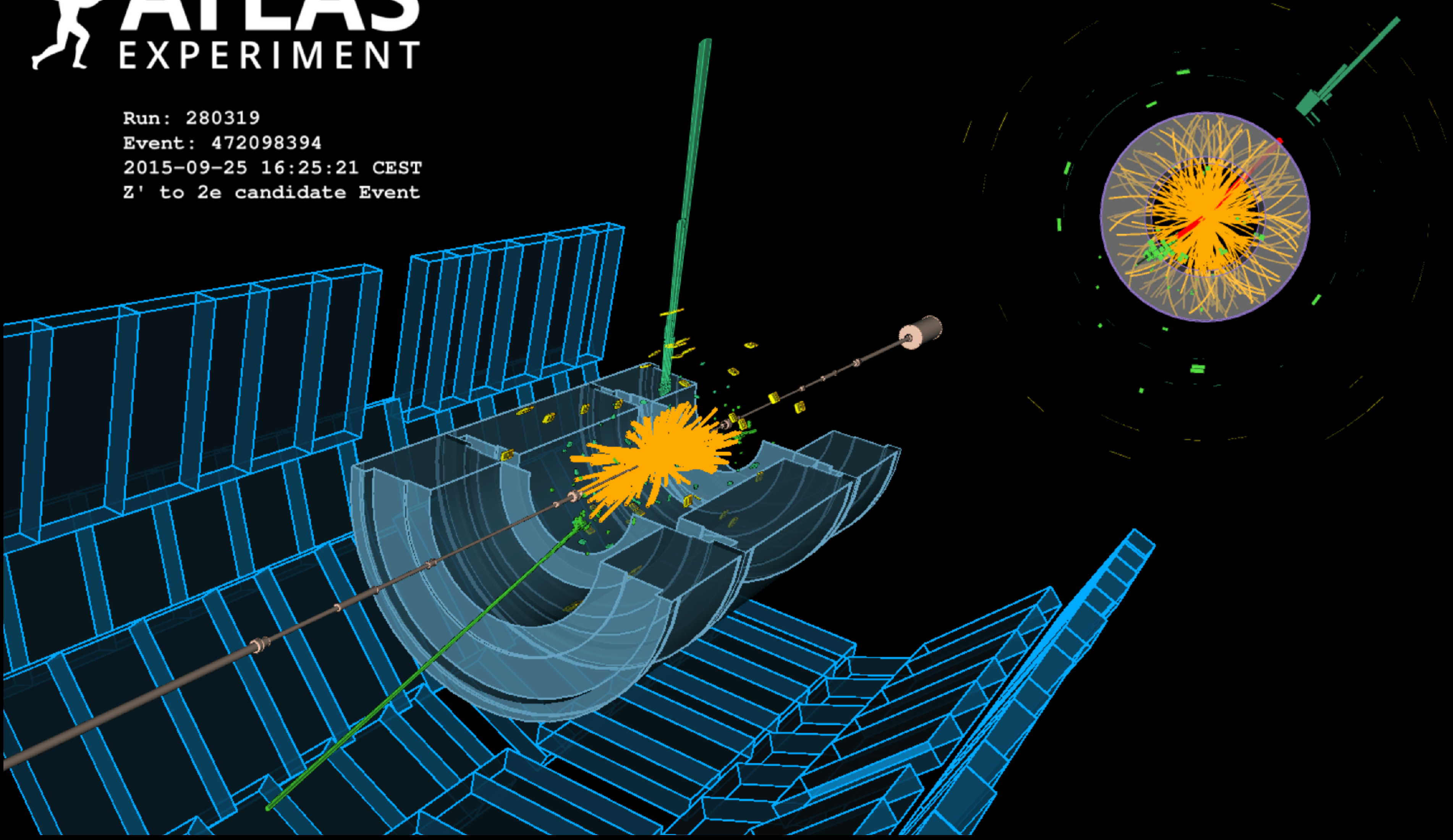
- Limits ranging from 3.4 to 4 TeV

Di-Electron Event

High Mass Dielectron

$ET_1 = 370$ GeV $ET_2 = 246$ GeV

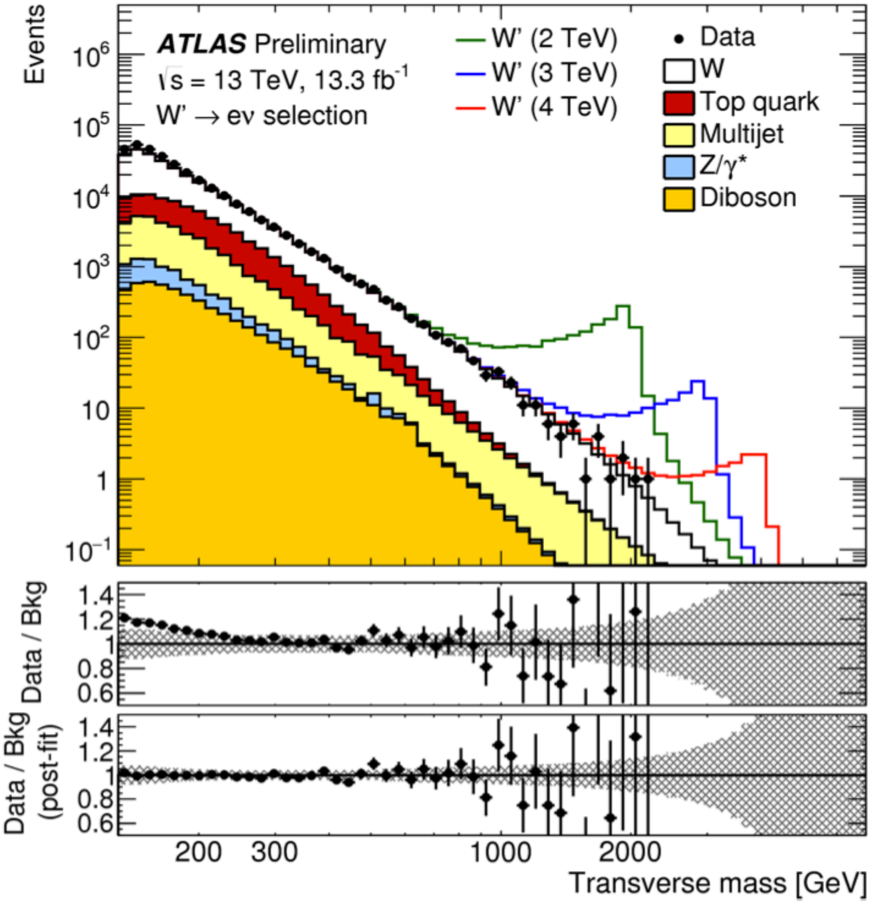
$m_{ee} = 1.8$ TeV



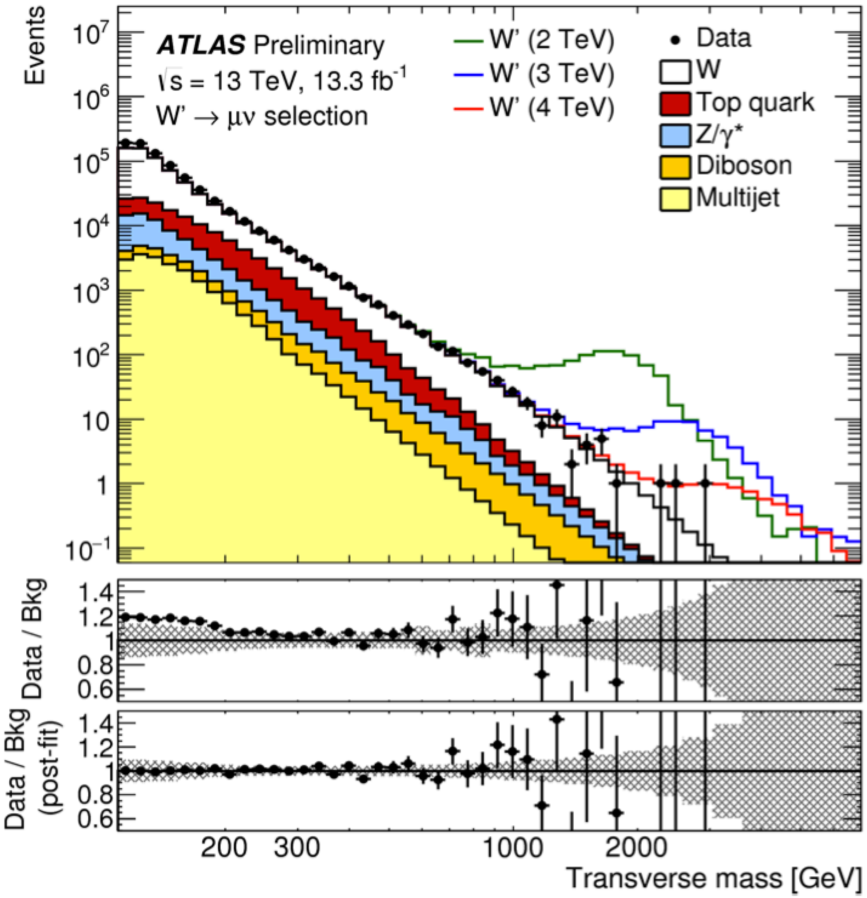
Run: 280319
Event: 472098394
2015-09-25 16:25:21 CEST
Z' to 2e candidate Event

Search for High Mass W’

ATLAS-CONF-2016-061



Electron channel



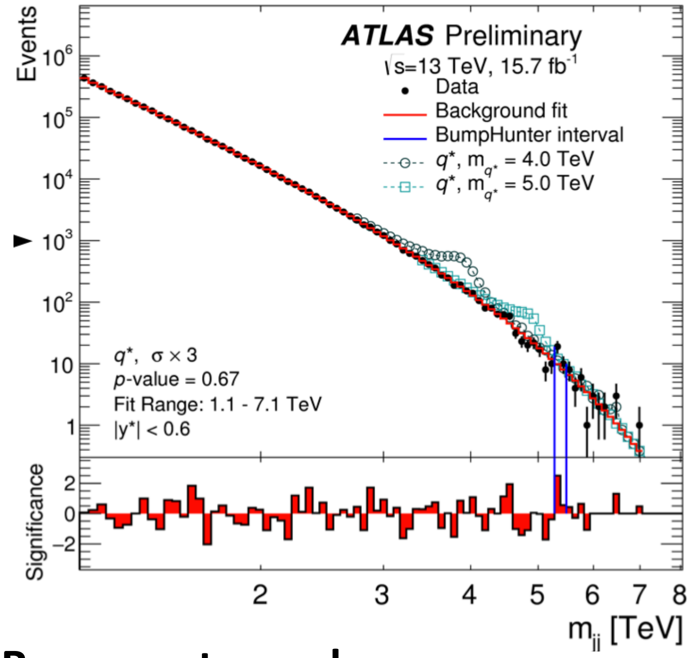
Muon channel

- Importance of systematic uncertainty related to MET in the low mass
- Similarly the extrapolation of the efficiencies and the calibration at very high pT is very important: not a low hanging fruit!

Di-jet Searches

Resonant and non resonant search

ATLAS-CONF-2016-069



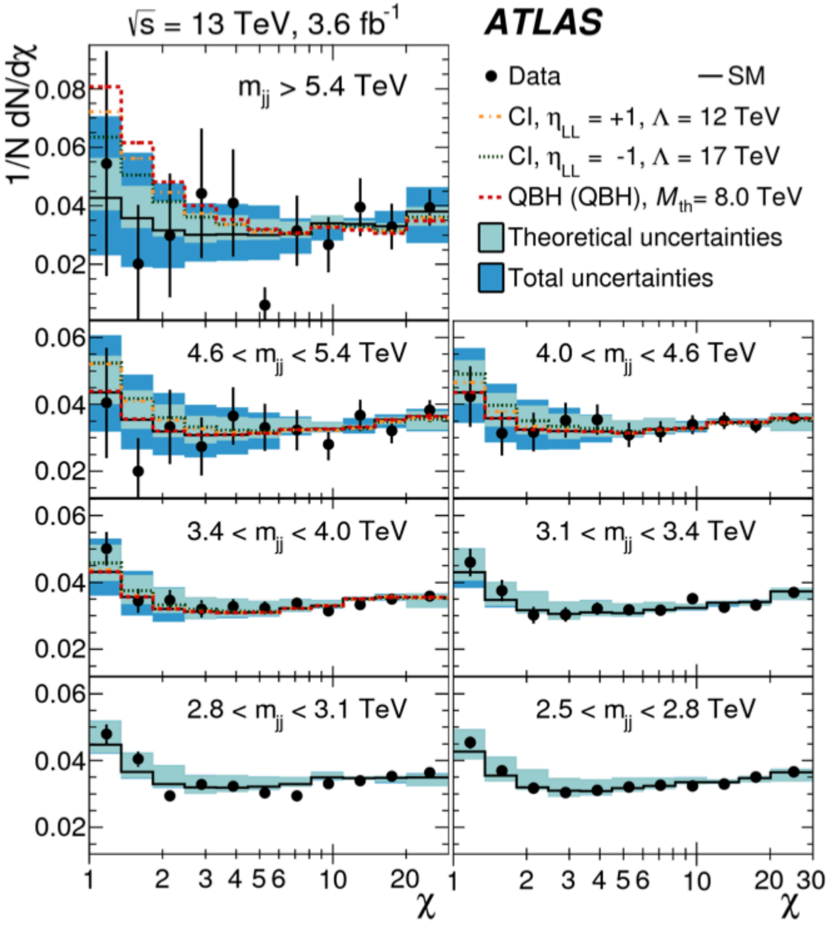
Resonant search

Hunt for a bump, if none interpret in terms of limits using specific signal models.

Non-resonant search

Search for distortions of the dijet angular distributions in bins of di-jet mass.

Interpret in terms of limits on Contact interaction.



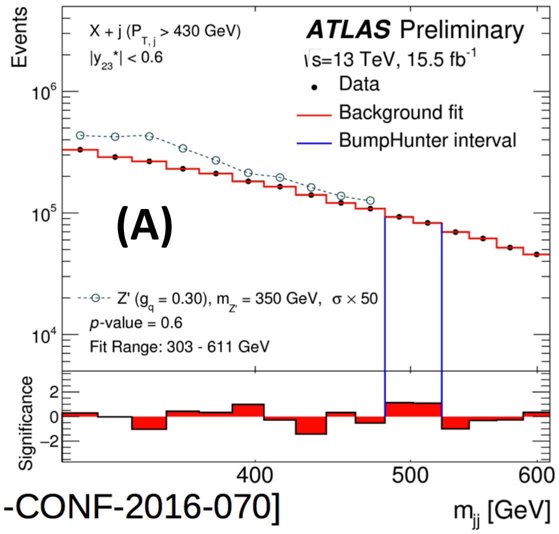
$$\chi = e^{2|y^*|} \sim \frac{1 + \cos\theta^*}{1 - \cos\theta^*}$$

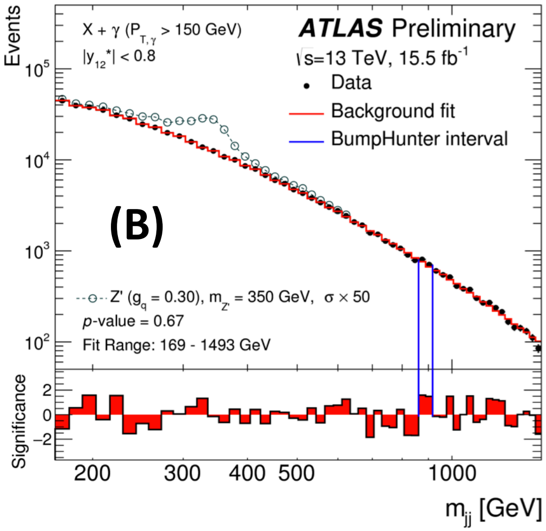
Limits on CI mass scale of up to 20 TeV

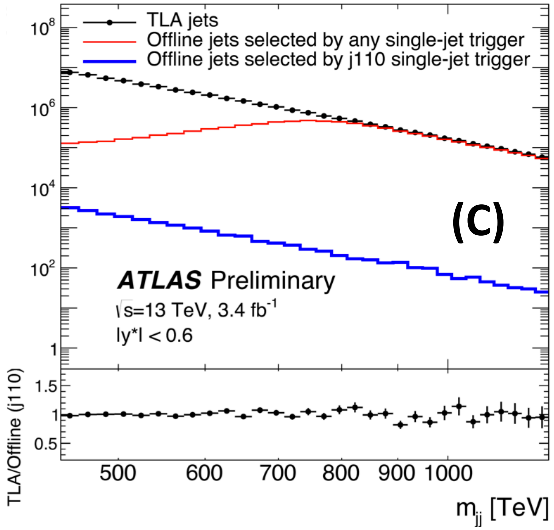
See also Javier'stalk

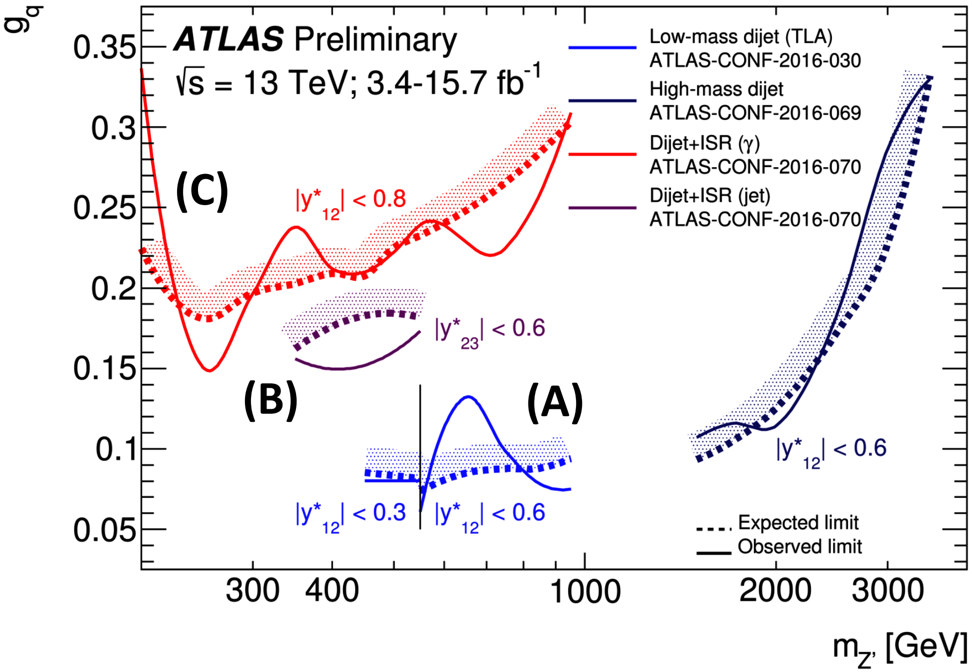
Di-jet Searches

Investigating the intermediate mass range









(A) Trigger Level Analysis

Only small necessary information is stored and the analysis is done at trigger level, calibration is particularly non trivial in this case.

ATLAS-CONF-2016-030

(B) ISR with photon ATLAS-CONF-2016-070

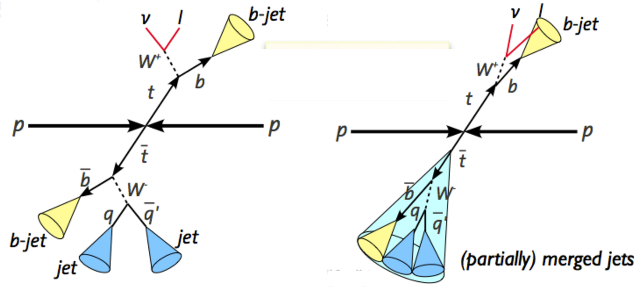
Use ISR photon for triggering and look at recoiling jet pairs

(C) ISR with jet ATLAS-CONF-2016-070

Use higher jet activity to reach lower masses using an ISR jet

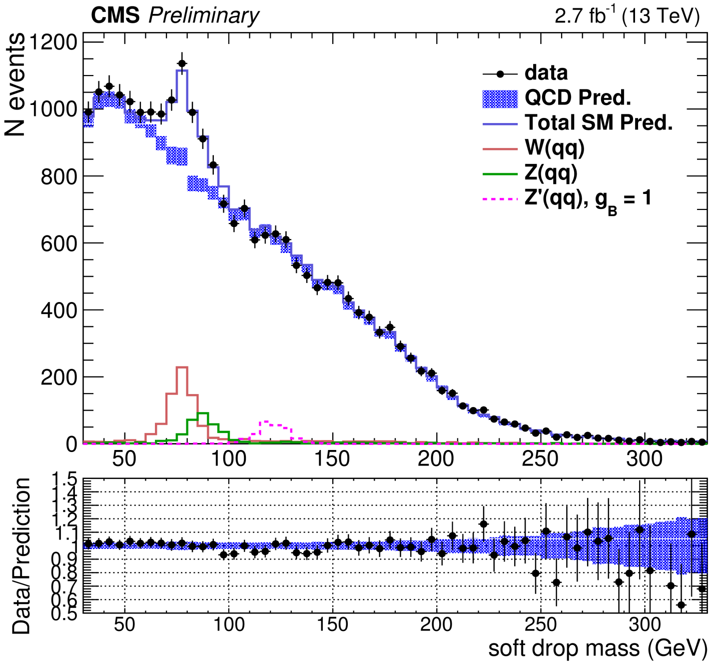
Jet Substructure

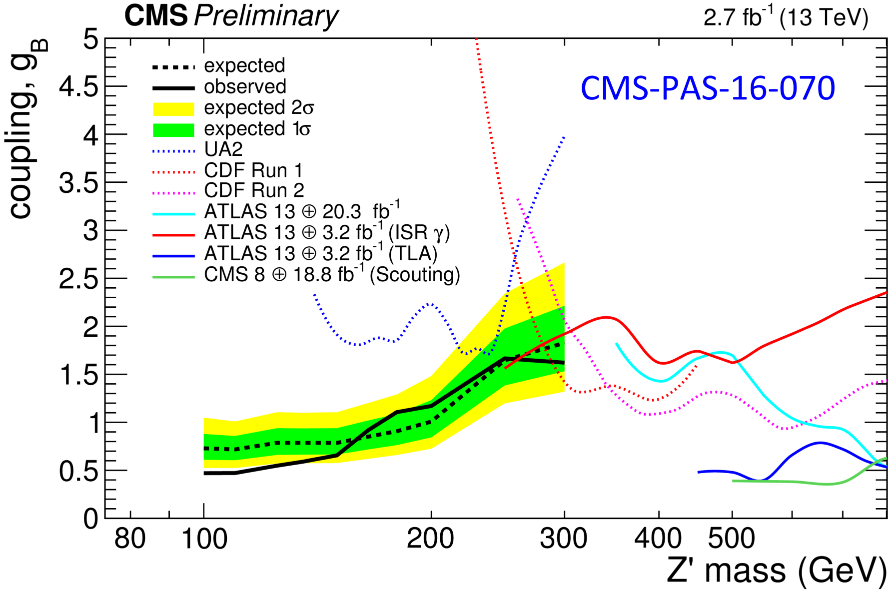
See Salvatore and Andrew's talk



Nominal boson tagging algorithm

- Large R-jet algorithms used to tag hadronic decays of particles such as W, Z, Higgs and the top.
- Algorithms use substructure of jets.
- Pileup subtraction is very important, and a large number algorithms have been developed.
- Overall performance is very impressive!



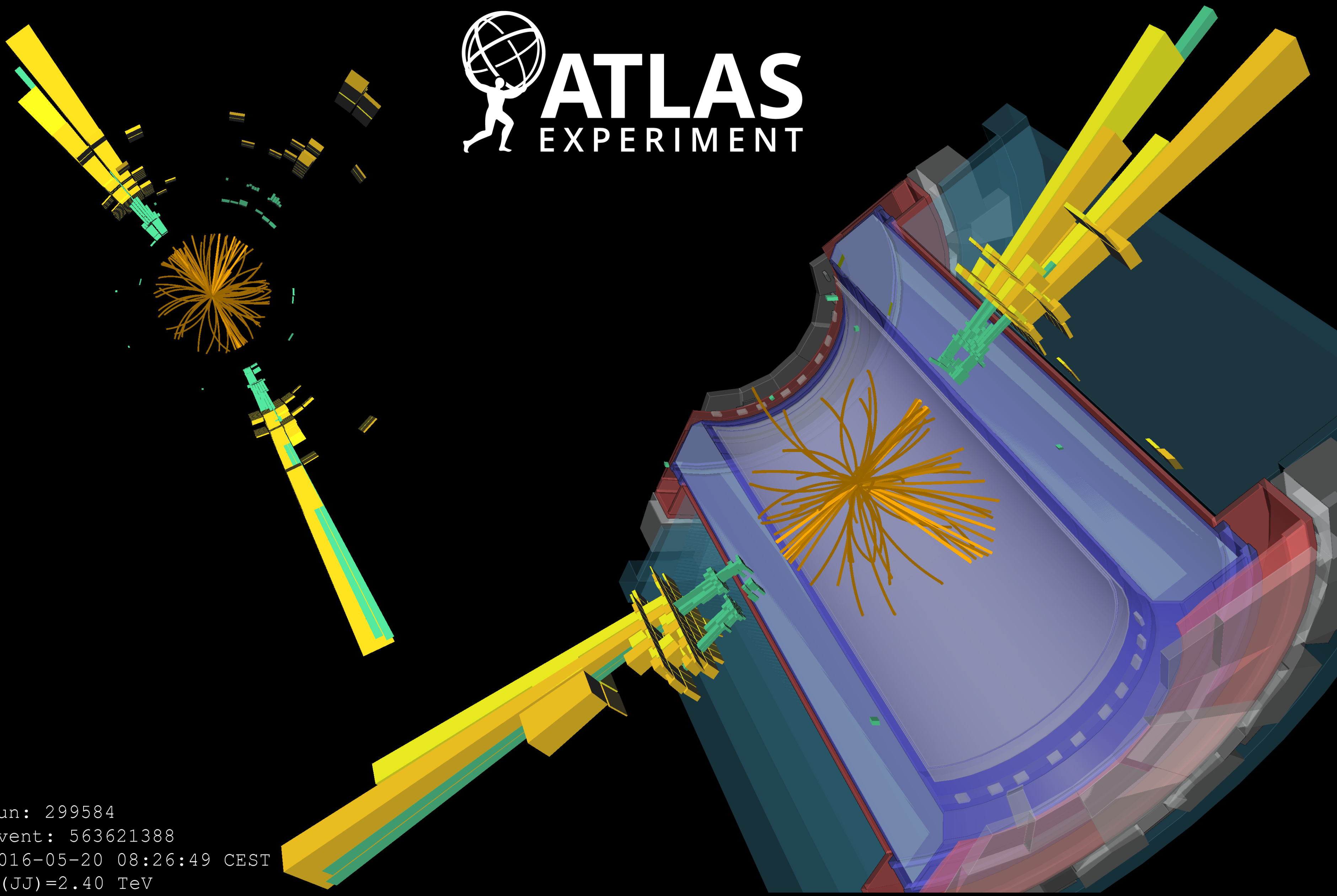


Di-boson full hadronic event

High Mass Di-Fatjet

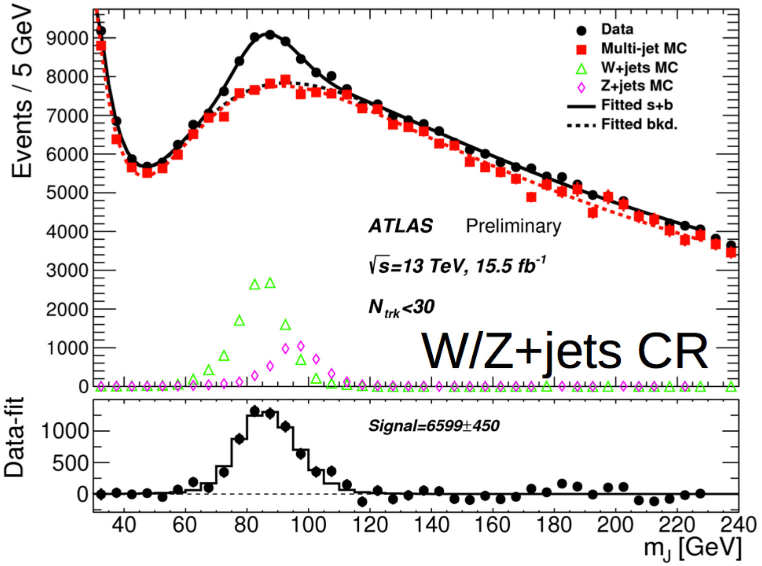
ET_1 = 370 GeV ET_2 = 246 GeV

m = 1.8 TeV



Run: 299584
Event: 563621388
2016-05-20 08:26:49 CEST
M(JJ)=2.40 TeV

Jet Substructure



Simple selection of inclusive jet!

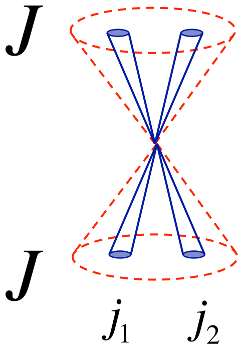
Nominal boson tagging algorithm

- Large R-jet algorithms used to tag hadronic decays of particles such as W, Z, Higgs and the t
- Algorithms use substructure of jets.
- Pileup subtraction is very important, and a large number algorithms have been developed.
- Excellent overall performance

- Anti-kT R=1.0
- Trimming: fcut = 5% and Rsub = 0.2
- pT dependent (energy correlation ratio) D2 selections for W and Z separately (Multijet reduction by 40 – 70)

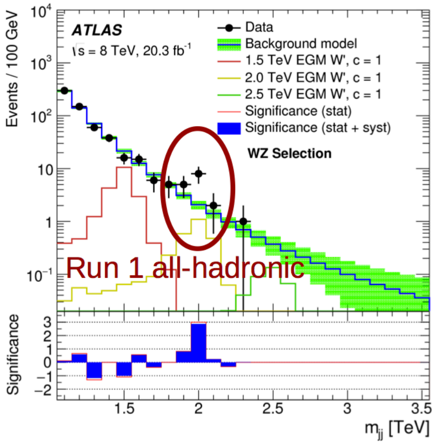
Diboson search

VV to JJ

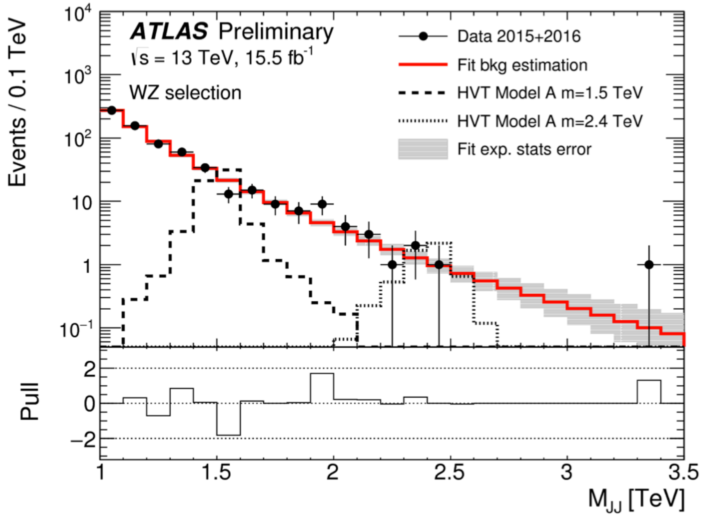


Modest excess Run-1

observed at Run 1

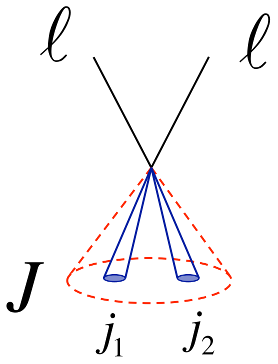


ATLAS-CONF-2016-055



Searches for a **Resonance** in **Diboson VV** Final States

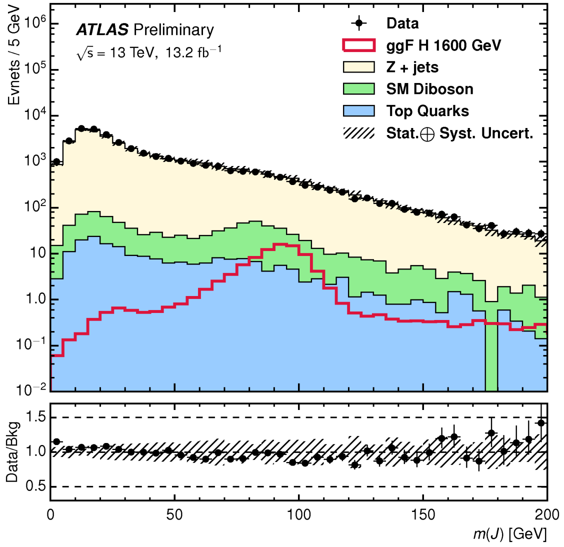
ZV (with Z to **dilepton**)



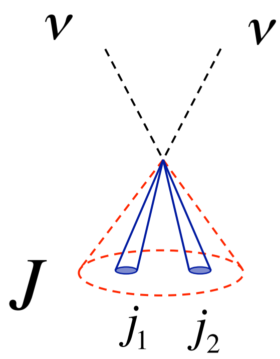
Backgrounds

Z-jets is the main background, estimated using MC and normalised to mJ sidebands

Diboson and top from MC

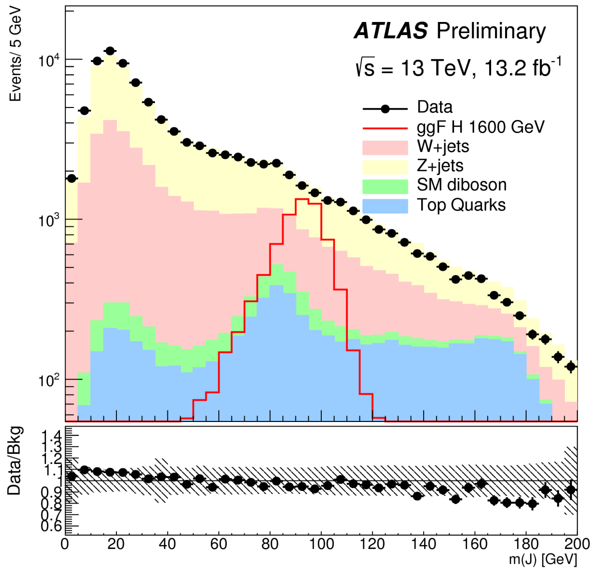


ZV (with Z to **vv**)

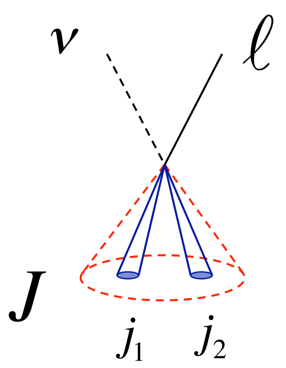


Backgrounds

Z-jets main background, W-jets and top are not negligible, these are estimated using CRs with 1 or 2 muons and one b-tag for the Top CR.



WV (with W to **lv**)

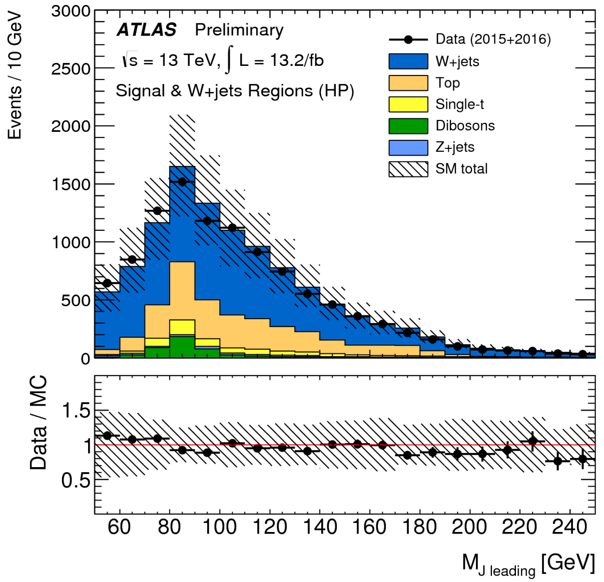


Backgrounds

Z, W and top shapes from MC

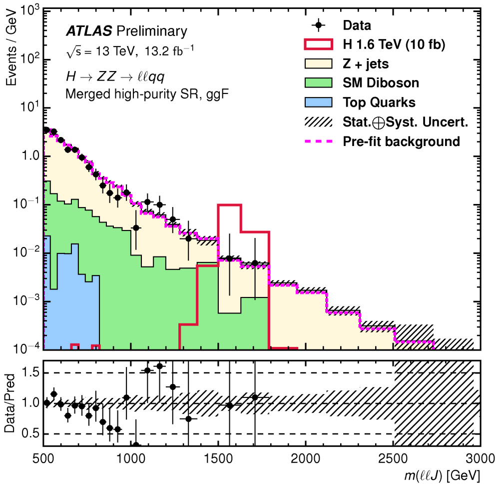
Diboson fully from MC

Multijet shape from loose lepton ID

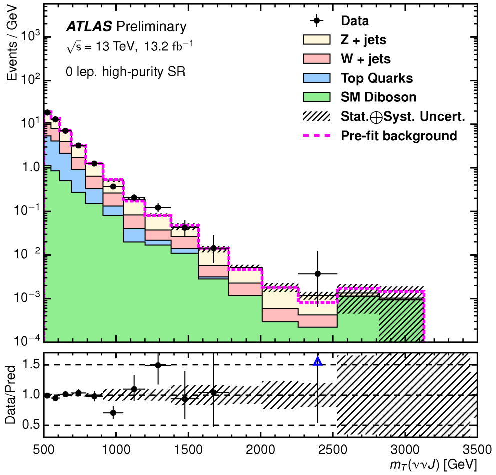


Searches for a **Resonance** in **Diboson VV** Final States

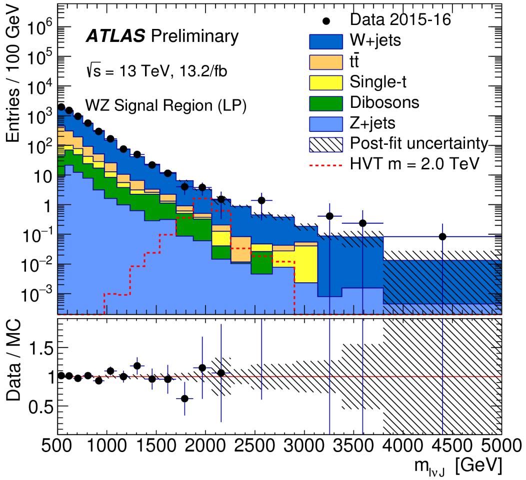
ZV (with Z to **dilepton**)

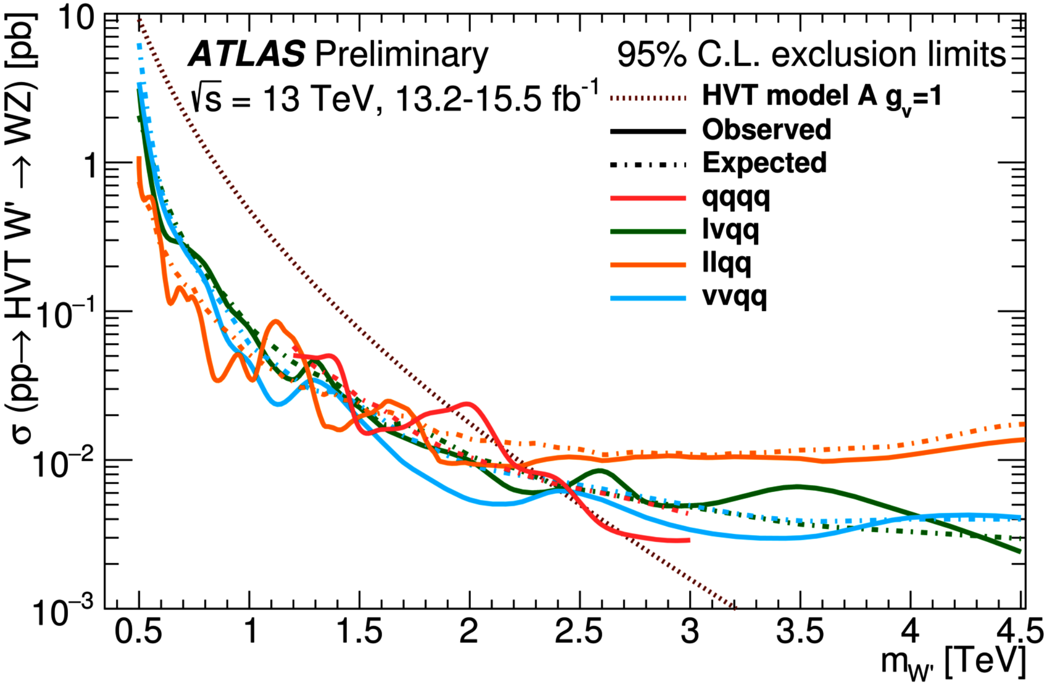


ZV (with Z to **vv**)



WV (with W to **lv**)





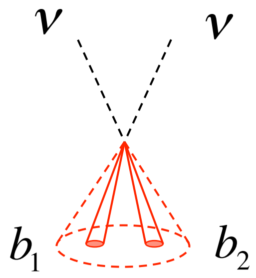
Results

Analyses have similar sensitivities ranging between **2.2 TeV** and **2.5 TeV** for HVT additional vector bosons

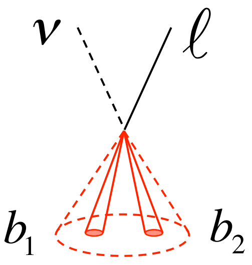
- No significant excess observed, limits are set in these scenarios
- Interpretations also in Higgs and Graviton hypotheses

Searches in **Diboson VH** Final States

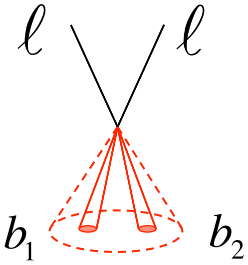
Leptonic channels: 6 regions 0L, 1L-MET and 2L-MET with at least two jets and 1 or 2 b-tags (2 b-tags harder to distinguish at high pT) – done with 2015 data.



ZH (with **Z to vv**)

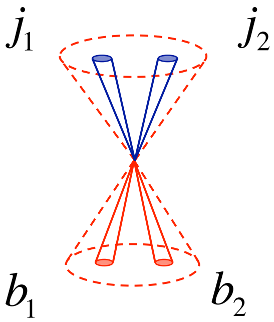


WH (with **W to lv**)



ZH (**Z to ll**)

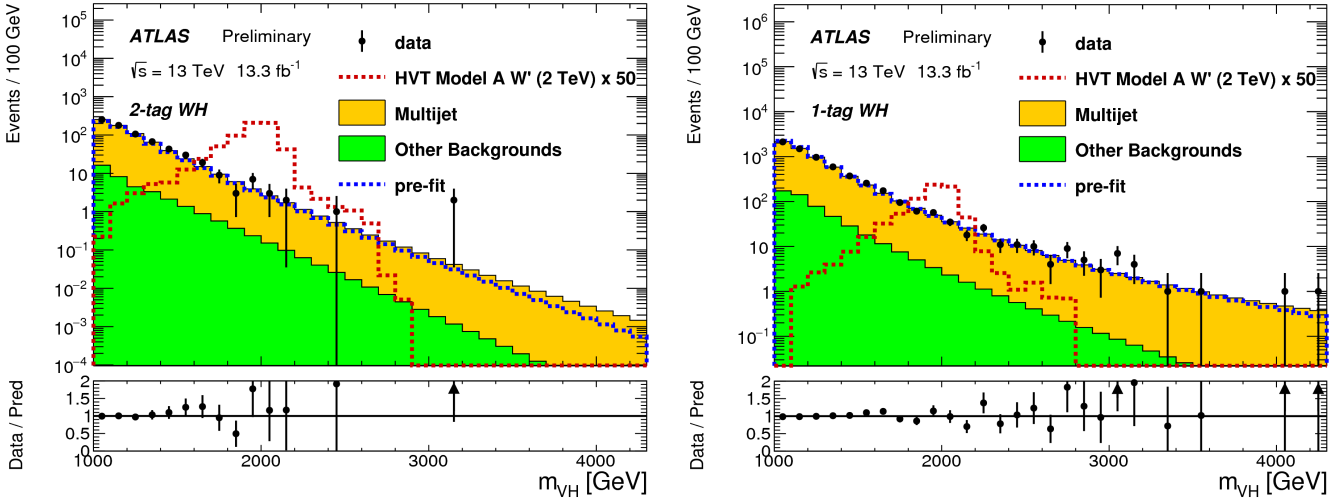
Fully hadronic channel:



ATLAS-CONF-2016-020

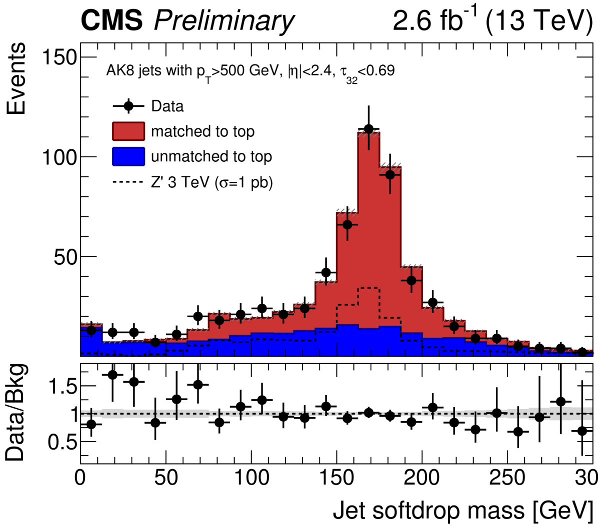
In boosted regime: W/Z tagging on one side and Higgs tagging on the other

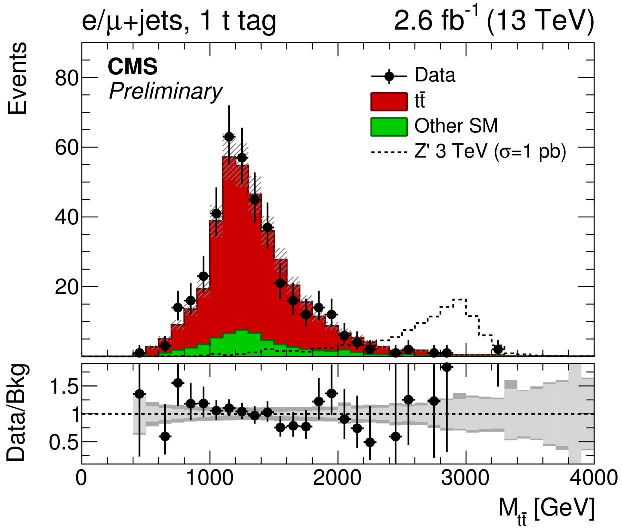
Slight excess observed in WH selection 3.5σ local and 2.5σ global at a mass near 3 TeV (for the time being it is the gathering of a few events near the tails of the distribution)



Top Pair Resonance Searches

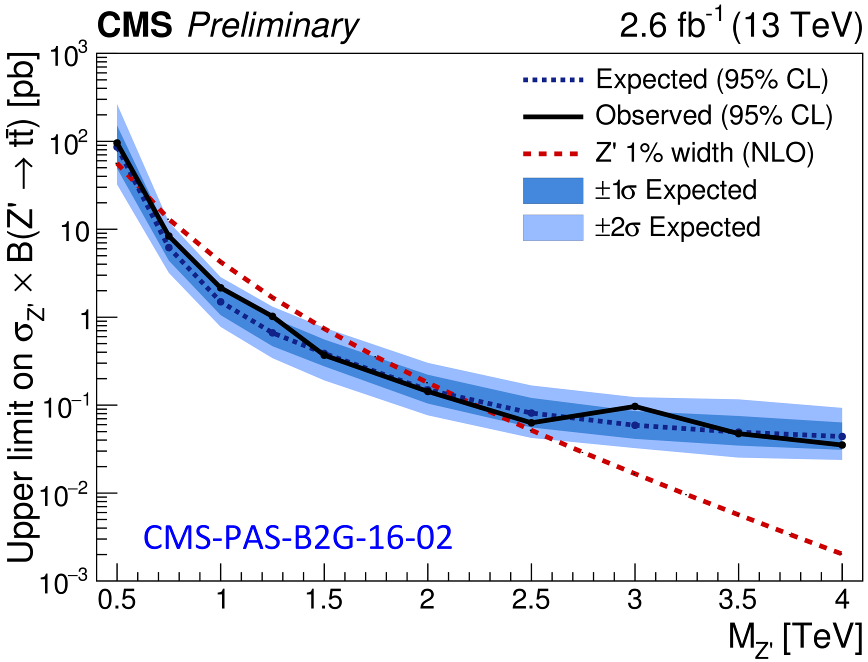
Using boosted jets substructure techniques





High mass top pairs are excellent to highlight the performance of top tagging techniques

The large number of top airs produced is very important to validate/calibrate the substructure reconstruction algorithms.



CMS-PAS-B2G-16-02

Limits ranging from 2.5 to 3.5 TeV (Depending on the assumed width of the Z')

Possible non-negligible interference signal and background neglected.

Searches for Vector Like Quarks

- Additional (sequential) 4th generation is ruled out by the Higgs couplings.
  Would be significantly changed in case of a 4th generation.

- Mass terms for fermions strongly interacting, i.e. Quarks which transform as $SU(2)_L$ are gauge invariant and therefore do not need to couple to the Higgs.

- Found in many models: Composite Higgs, extra dimensions, little Higgs.

- Complex channels looking for T(2/3), B(1/3): Ht+X, Wt+X, Wb+X, Zb+X, Zt+X (Performed at Run 2) so far and T(5/3) 4tops final state.

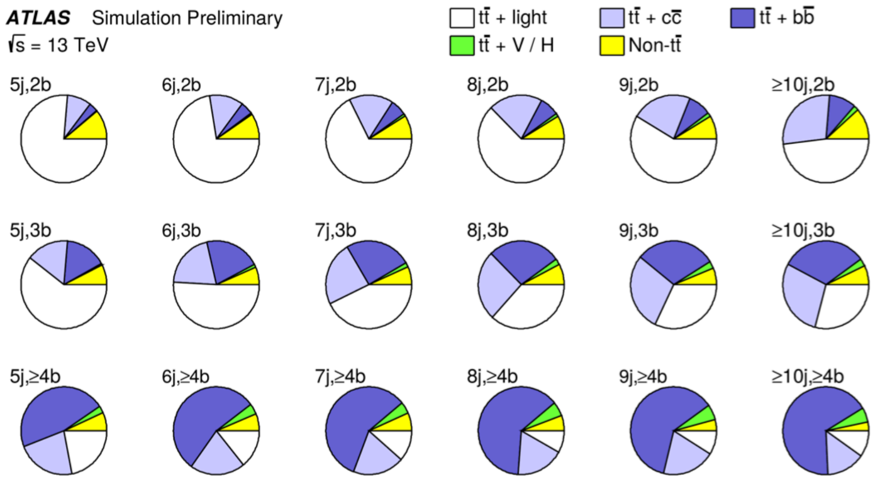
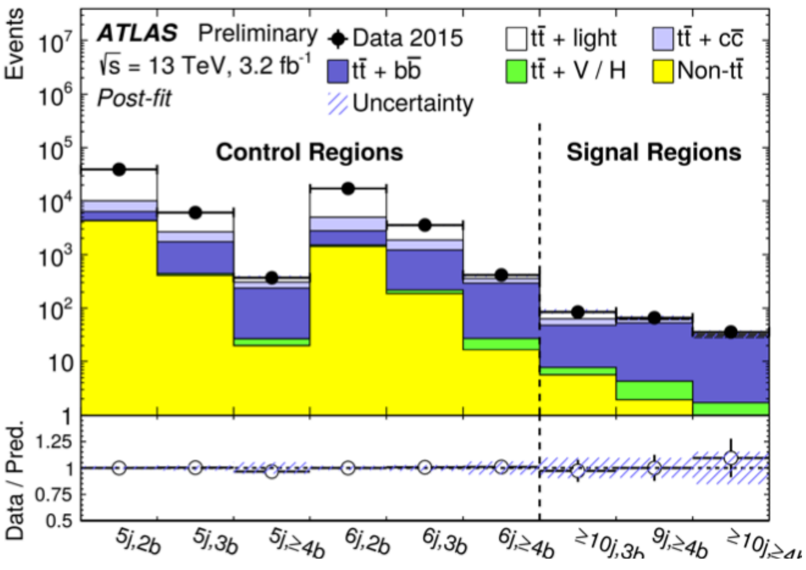


Illustration of the reach in complexity of signature with up to 10 jets with 4 b-tags.



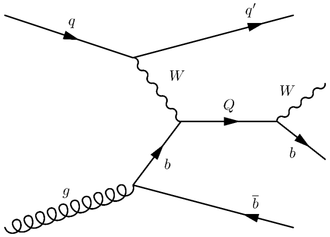
ATLAS-CONF-2016-020

VLQ Searches with the 2016 dataset

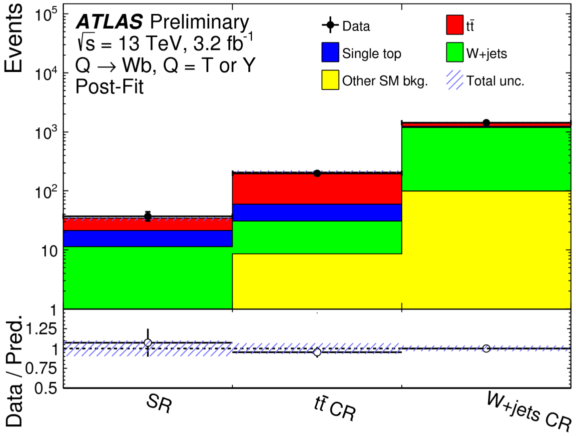
Q (Wb) Channel

ATLAS-CONF-2016-072

Selection of one lepton and at least one very high ET jet (in excess of 350 GeV).



Background dominated by top (and W-jets), estimated from control regions.



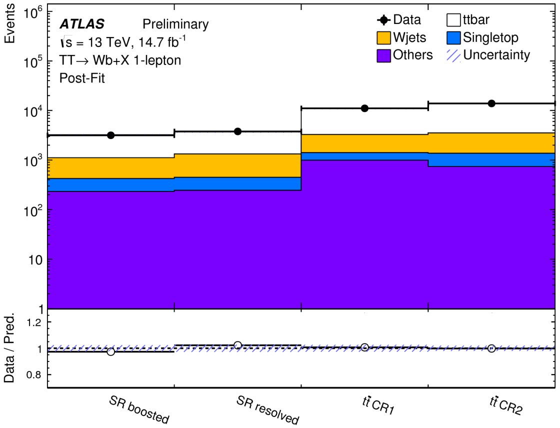
Q pair (Wb) Channel

ATLAS-CONF-2016-102

Complex final state

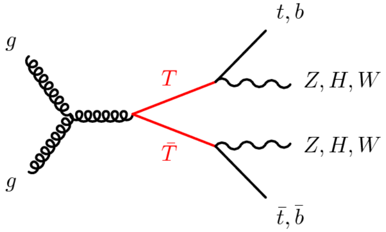
- One lepton
- MET > 60 GeV
- Boosted: 1-Large R jet and 3 Small-R jets
- Resolved: Four Small-R jets

Background Dominated by top events from a control region



Q pair (t,b - Z,H,W) Channel

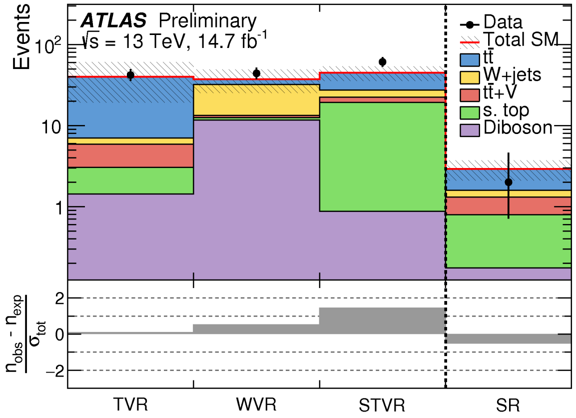
ATLAS-CONF-2016-101



Very complex final state

- One lepton
- MET > 350 GeV
- Four jets small-R jets (one b-tagged)
- Two large-R jets

Background dominated by top and single-top (and W-jets). W and tt from CRs, ST from MC.

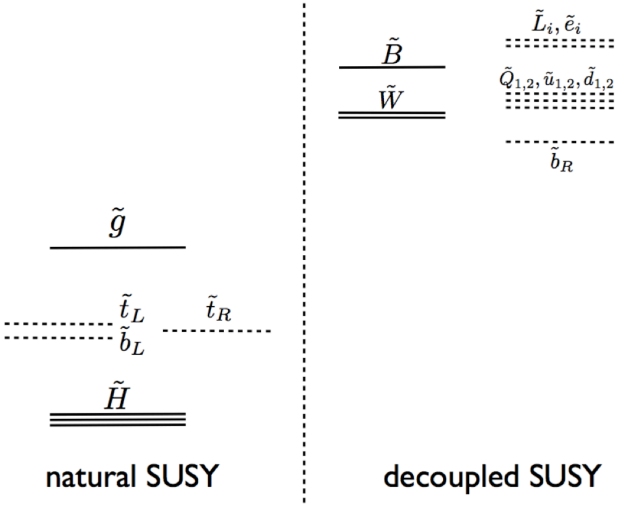


Searches for Supersymmetry

… and Additional Higgs bosons

SUSY in a tiny nutshell: too beautiful to be wrong! Solves (almost) everything

- Naturalness
- Unification of couplings
- Dark matter candidate
- Gravity (gauging SUSY) - mSUGRA



The paradigm scenario (still fully open at the LHC) of O(natural) SUSY

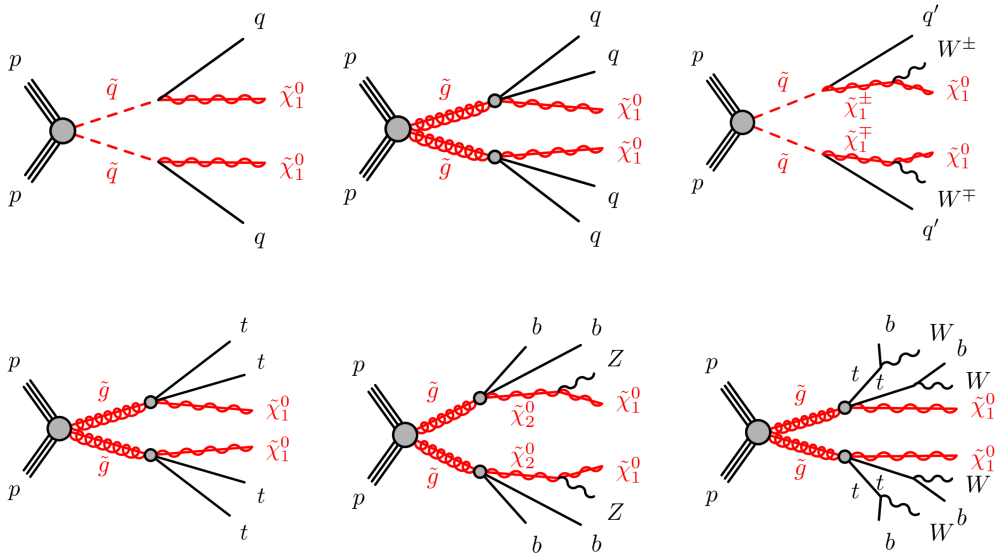
Strategy: Use simplified models to cover the widest possible variety of topologies. (Then more rigorously investigate the MSSM parameter space in the pMSSM, using the available searches.

Main searches:

- Gluino and squarks searches in (0L, 1L, 2L, 3L, b-jets, top, etc…)
- 3d generation searches in many channels for stop and sbottom (0L, 1L, 2L, taus, etc…)
- Searches for charginos and neutralinos “EW SUSY searches”, in (2L, 3L, 2taus, WZ, WH, etc…)
- Compressed scenarios: search for low pT stuff (soft leptons – trigger strategy is important, low pT b’s, etc…)

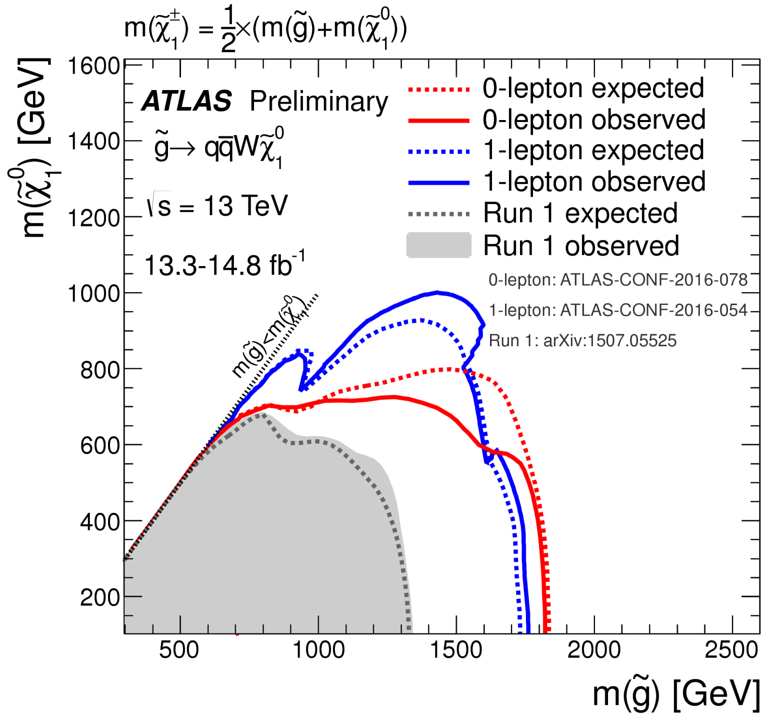
Strong SUSY Searches (Squarks and gluinos)

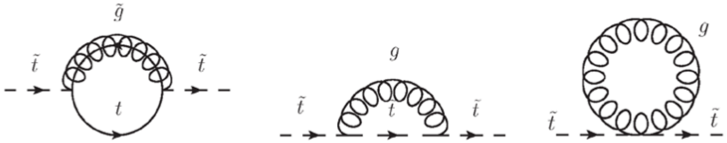
Very large number of possible topologies in the gluino (or squark) production:



Main channels covering all possibilities:

- 0L with N-jets (from 2 up to 10)
- 1L with N-jets (from 2 to 6)
- 2L, 3L and 4L with jets
- Multiple b-jets or top





Stop also a scalar requires light gluinos to be light enough: for gluinos > 1.8 TeV ~tuning of Factor of 30

Searches focus on corridors, compressed scenarios, or very specific corners of parameter space (pMSSM)

The 2L (OS-SF) strong production saga

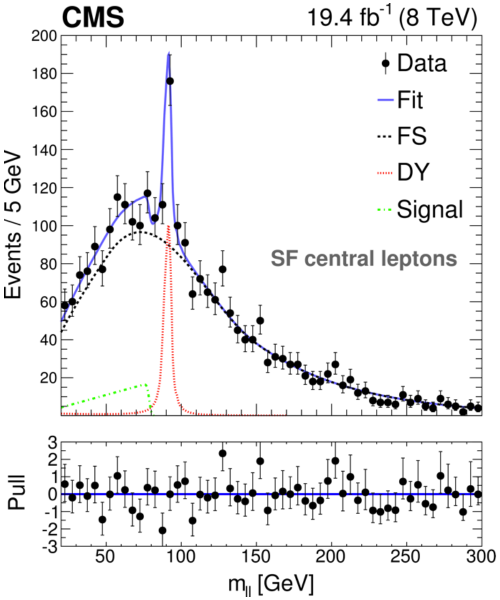
See Ben's talk

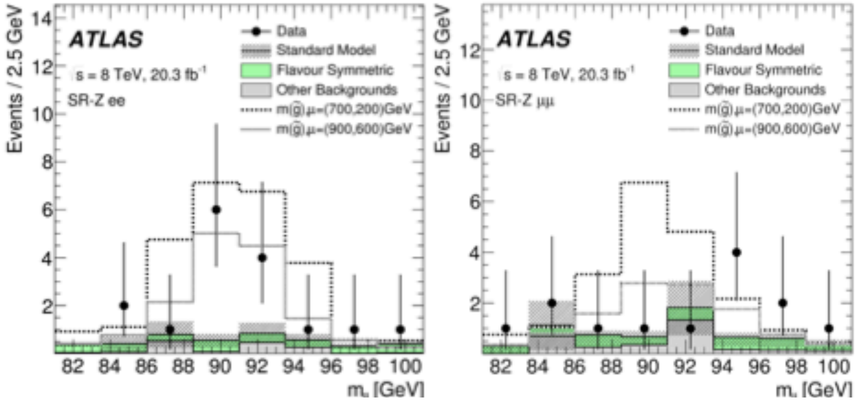
Run 1

Run 2

CMS Edge analysis

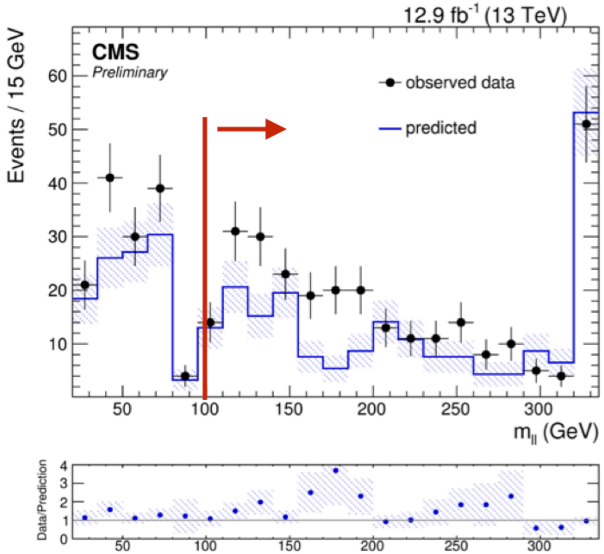
Below Z mass 2.2σ excess

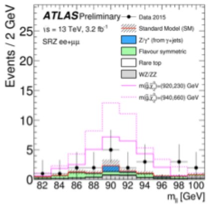




ATLAS On-Z Analysis 3.3σ excess

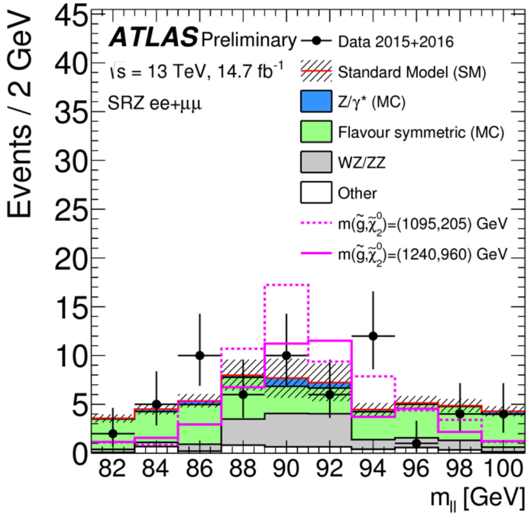
~3σ excess in the high mass





10 Events expected
20 observed 2.2σ

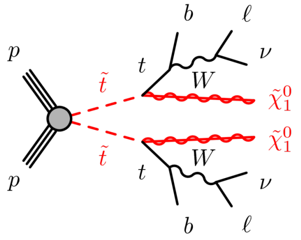
No excess



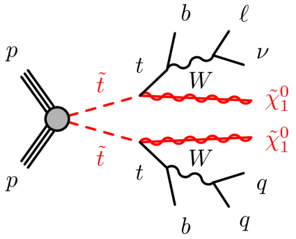
Stop Searches

$$\tilde{t} \to t\chi$$

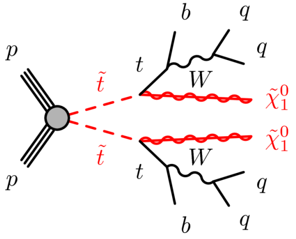
Stop 2-Leptons



Stop 1-Lepton

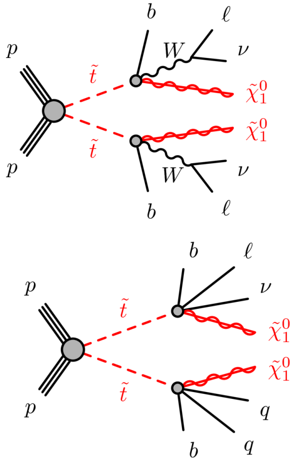


Stop 0-Lepton



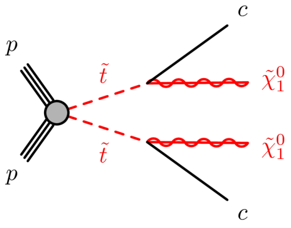
$$\tilde{t} \to bW\chi$$

Stop 1,2-Leptons

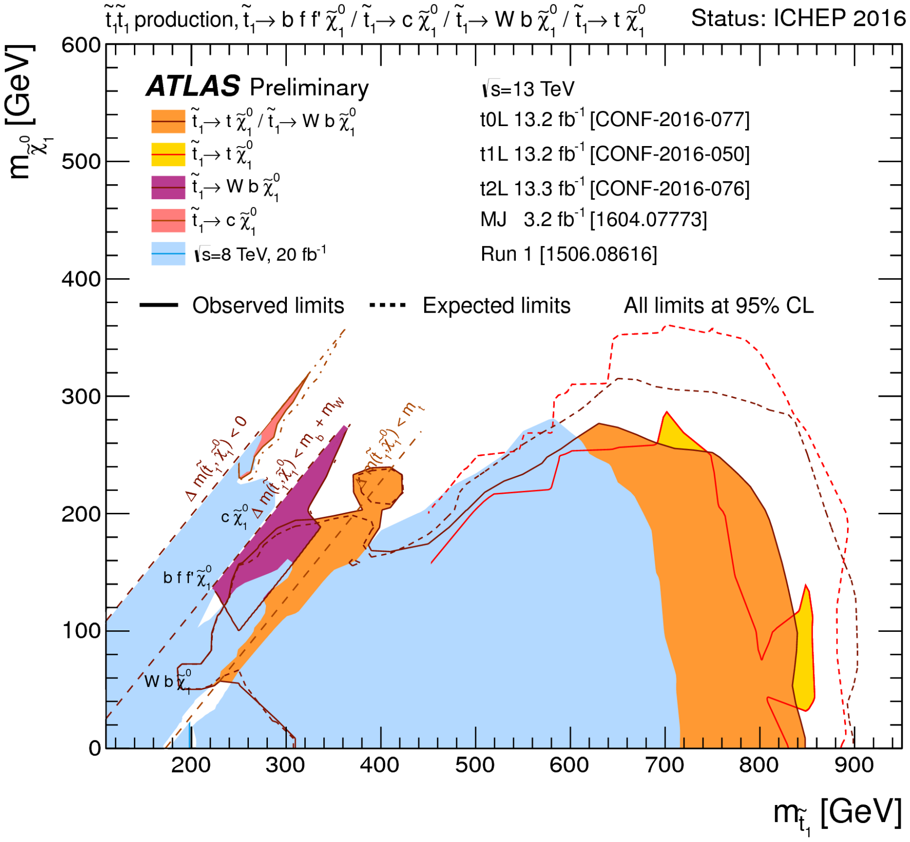


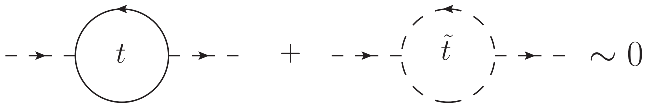
$$\tilde{t} \to c\chi$$

Mono-jet search



Large number of categories searched



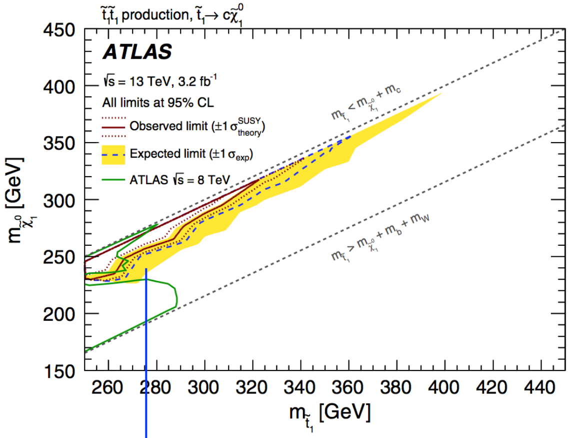


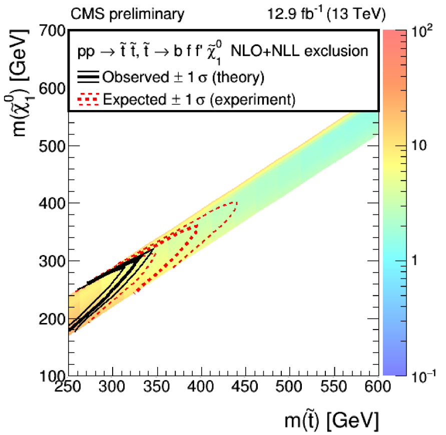
Not so natural SUSY: Stops > 800 GeV
~Tuning of factor 20

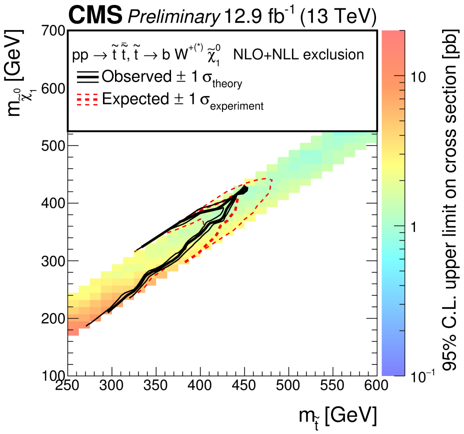
Stop Searches

Completing the Picture in Compressed Scenarios

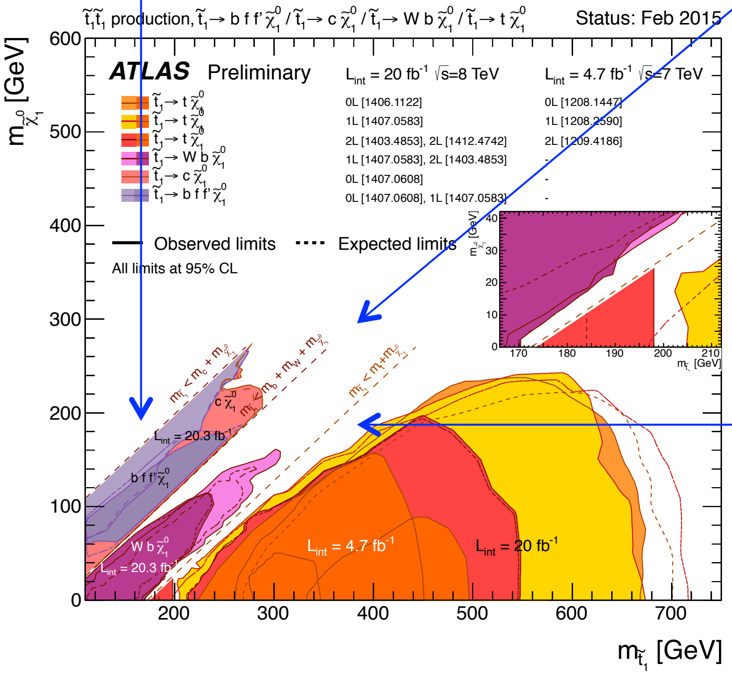
$$m_{\tilde{t}} \rightarrow m_c + m_\chi$$



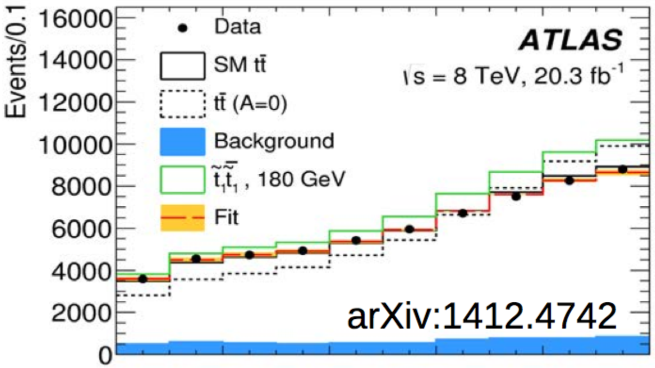




$$m_{\tilde{t}} \rightarrow m_W + m_b + m_\chi$$



$$m_{\tilde{t}} \rightarrow m_t + m_\chi$$



Spin correlations in tt production

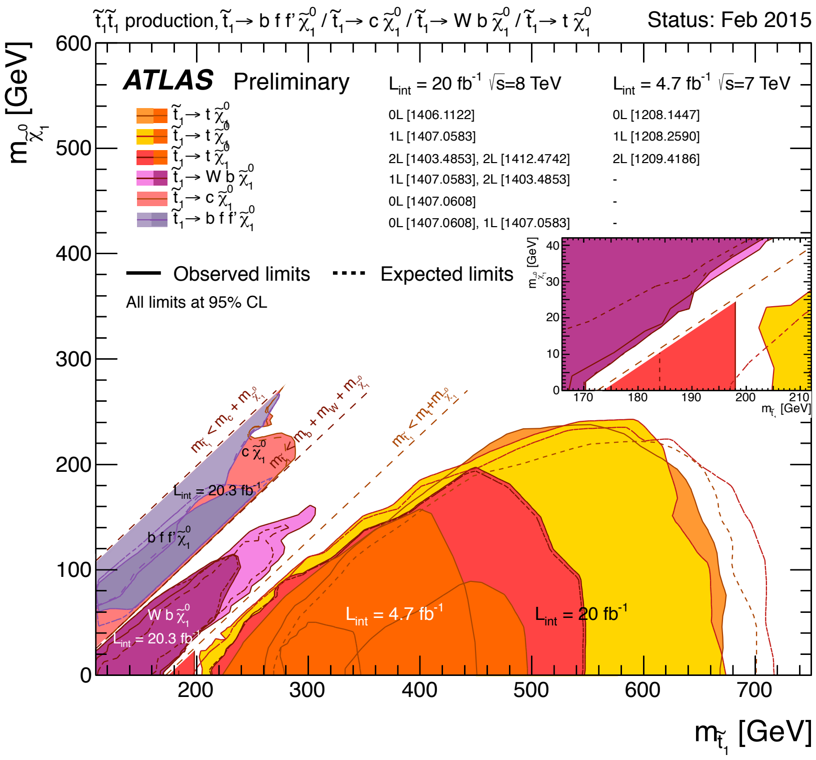
Stop Searches

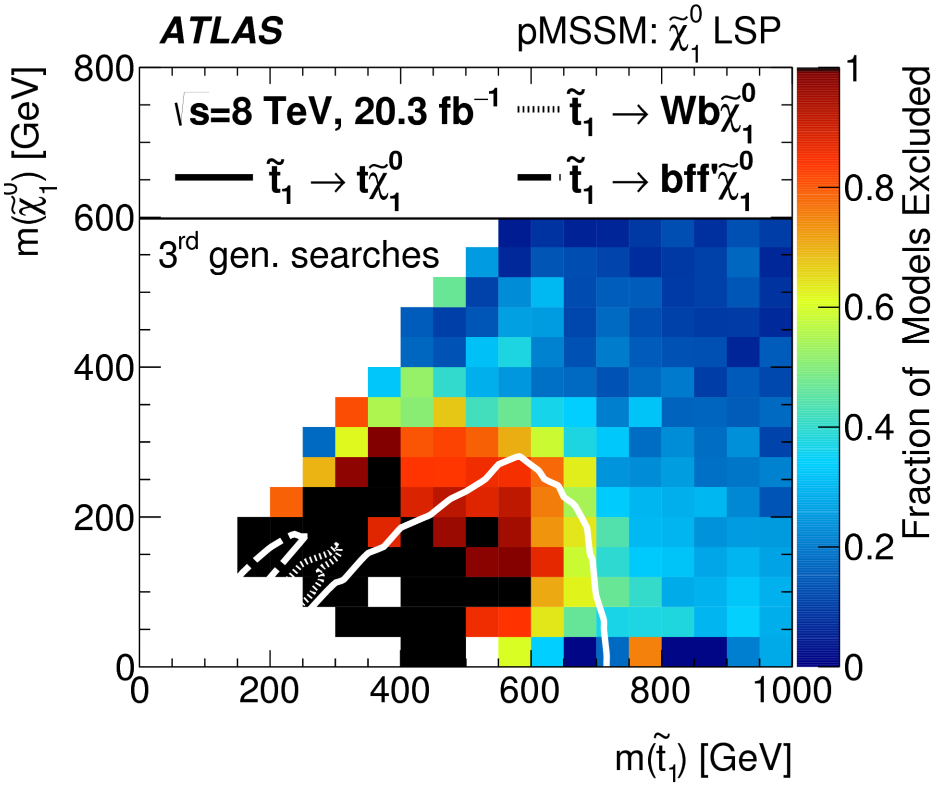
Completing the Picture in the pMSSM

pMSSM Survey

Survey of the 19 MSSM parameters using existing constraints

- 300 k models investigated
- 30 G evts generated
- Signal contamination in background normalization taken into account





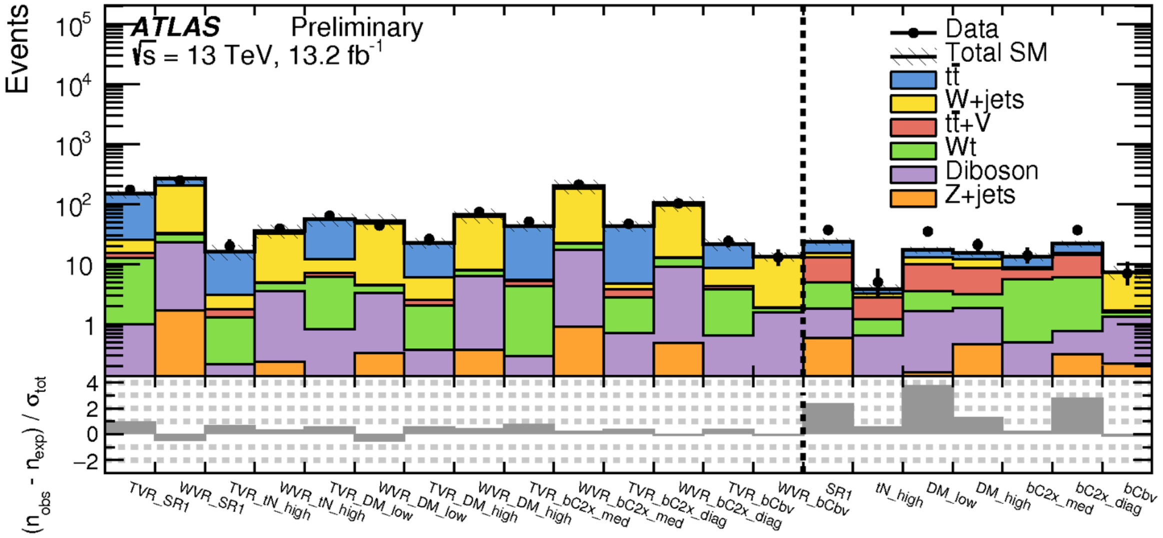
Experimental constraints effectively cover the excluded region well in the pMSSM

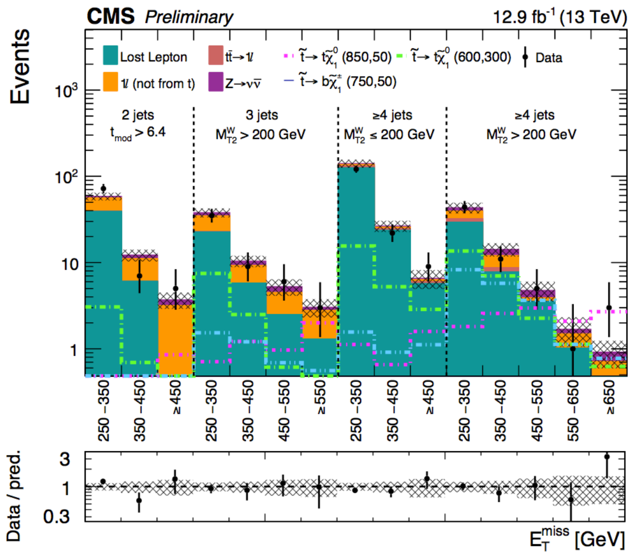
Example SUSY 1L Stop Searches

Search done in many categories with different kinematic requirements:

- 1 electron or muon
- 4 jets or more and 1 or 2 b-tags
- Intermediate to large MET and transverse mass
- Several additional kinematic criteria

Categories are correlated!





In ATLAS an excess is seen in two regions with four jets (1b) and intermediate/high MET 260-300 GeV with a p-value of 3.3σ

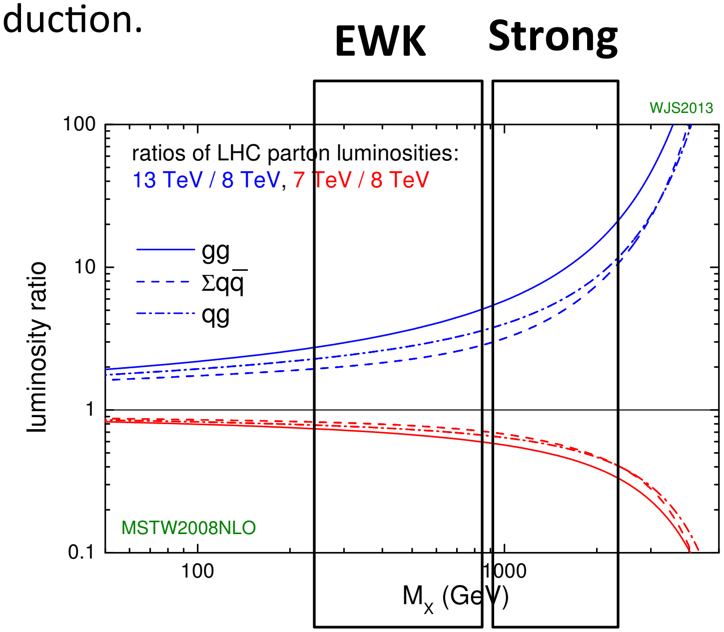
No excess seen in CMS for similar topology

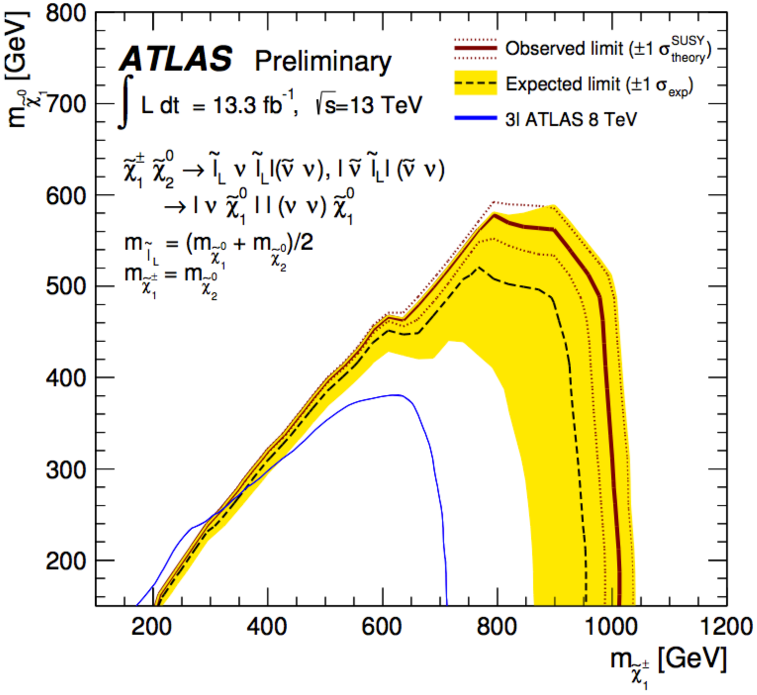
Electroweak Production

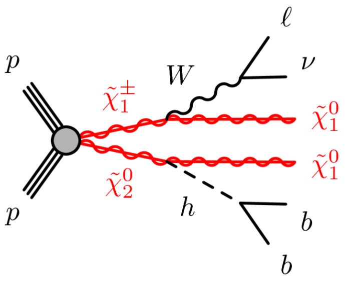
Search for Neutralinos, Charginos and sleptons:

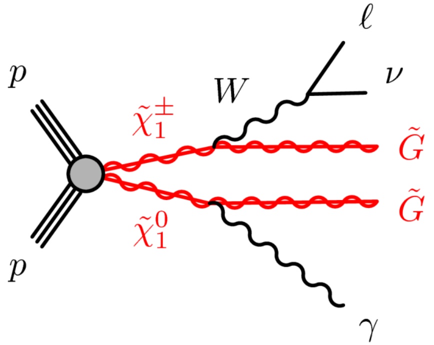
EW production with smaller cross section required a minimum amount of luminosity.

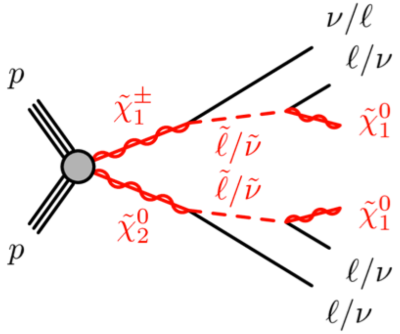
Topologies with 1 or 4 leptons (including taus) in the final state and final states with photons
And typically less jet activity than the strong production.





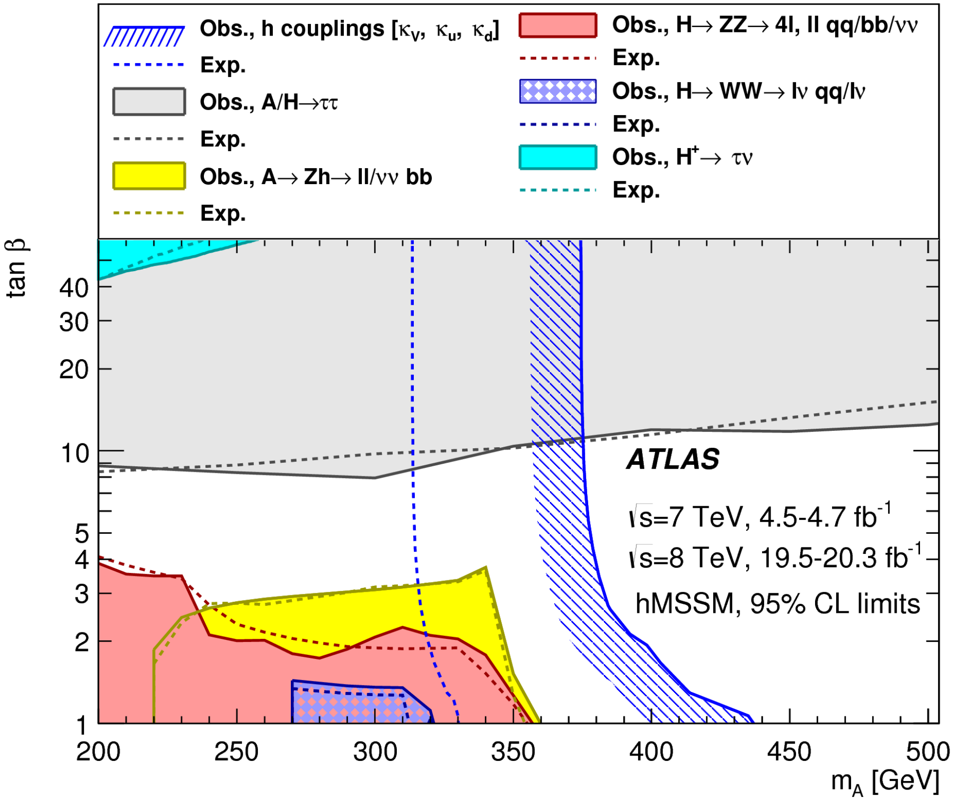


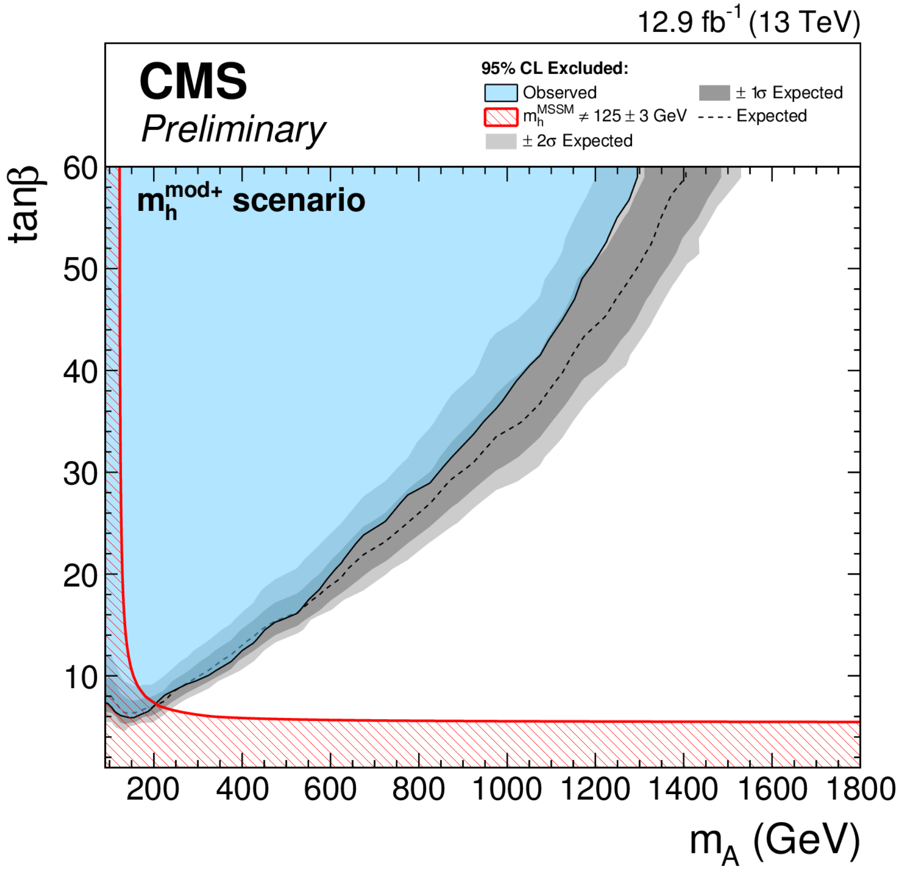


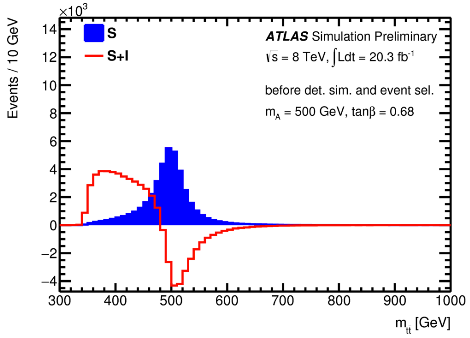


Searches for Additional Higgs bosons

MSSM needs fine tuning in order to accommodate the Higgs mass







- Complementarity between Higgs couplings and direct searches
- Complete the low tan beta region important
- Searches in tt resonances also important (Interference, not yet very sensitive)

Searches for Additional Higgs bosons

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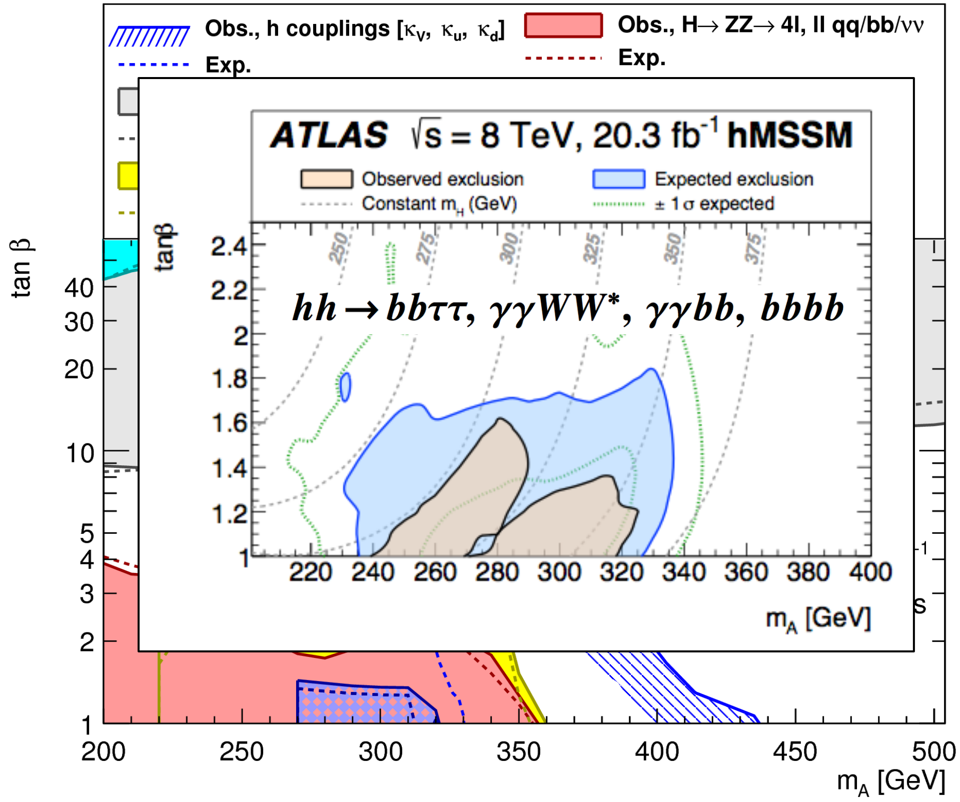
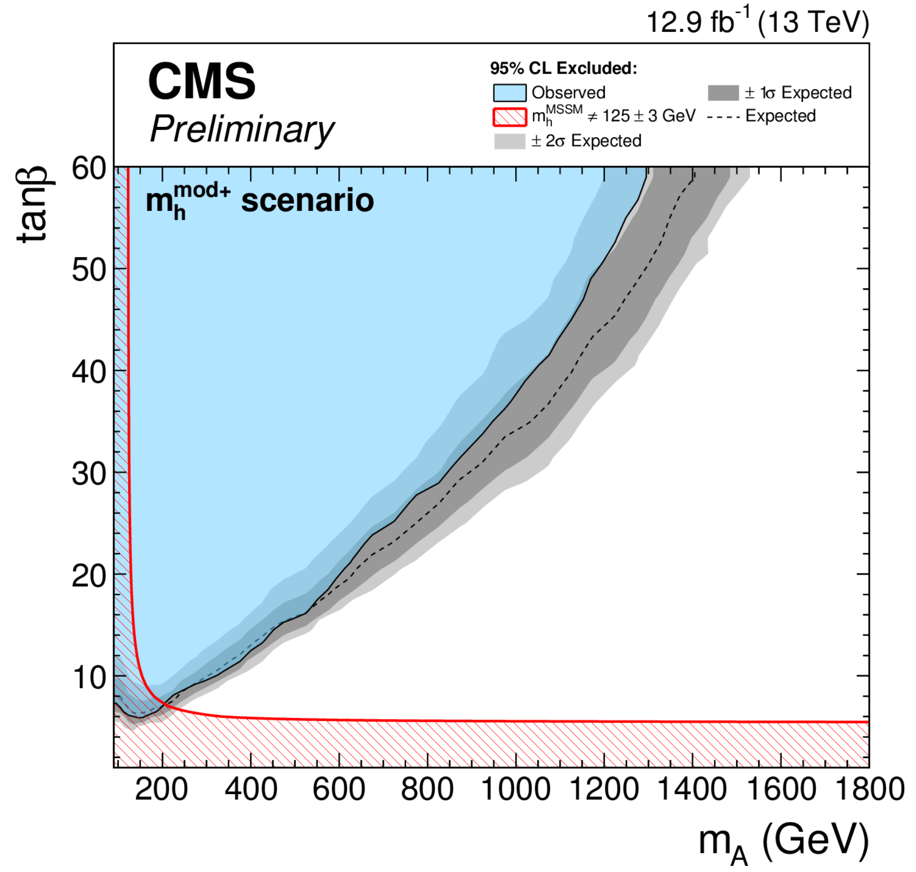
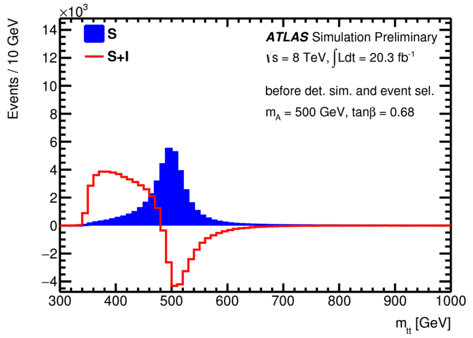






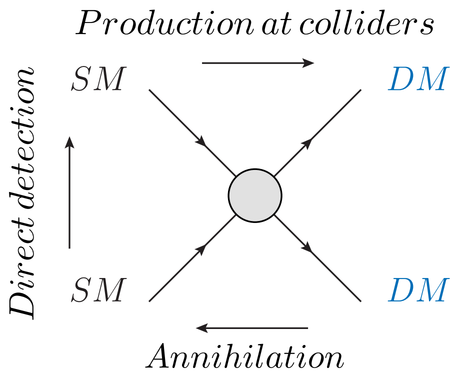
- Complementarity between Higgs couplings and direct searches
- Complete the low tan beta region important
- Searches in tt resonances also important (Interference, not yet very sensitive)

Dark Matter Searches

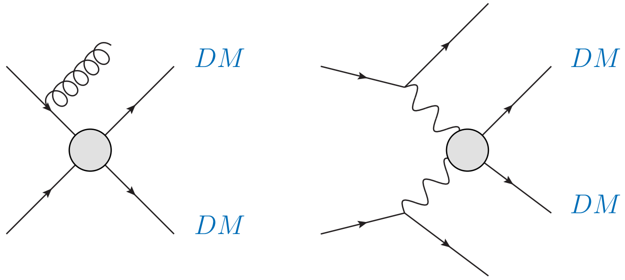
See Jim's talk

Complementarity

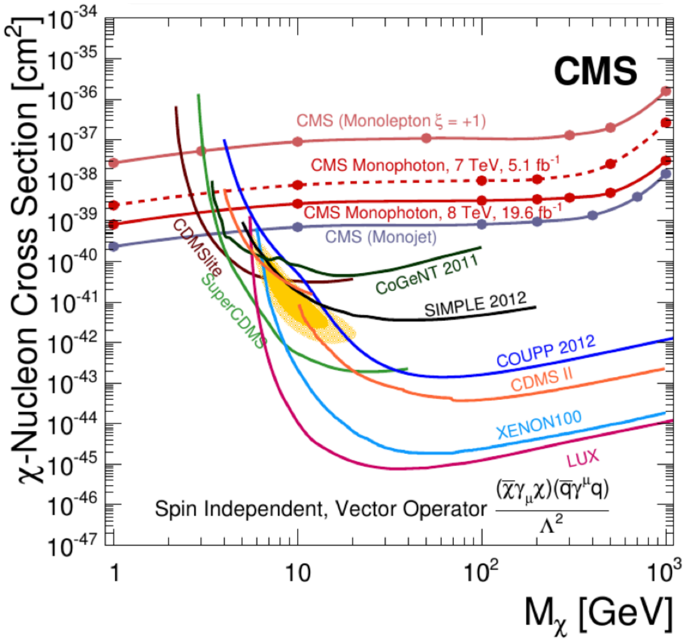
Of course ourstanding if seen in a lab!



LHC more typical scenarios



At Run 1 extensive use of EFT approach allowing to compare LHC results with direct detection



EFT approach is limited to very heavy mediator masses, above O(fewTeV)

Large effort to extend framework to include accessible mediator, important for optimized/ more specific DM searches.

A successful effort to produce a prioritized and compact set of simplified models:

DM Forum benchmarks (LHC Exp. and Theory): http://arxiv.org/pdf/1507.00966.pdf

The Mono-Jet Search

Phs. Rev. D94 032005

Selection requirements

- Trigger in this analysis MET>70 GeV (unprescaled)
- Reconstruction level MET above 250 GeV
- At least one jet of 250 GeV (up to four jets)
- MET should be isolated from the jets

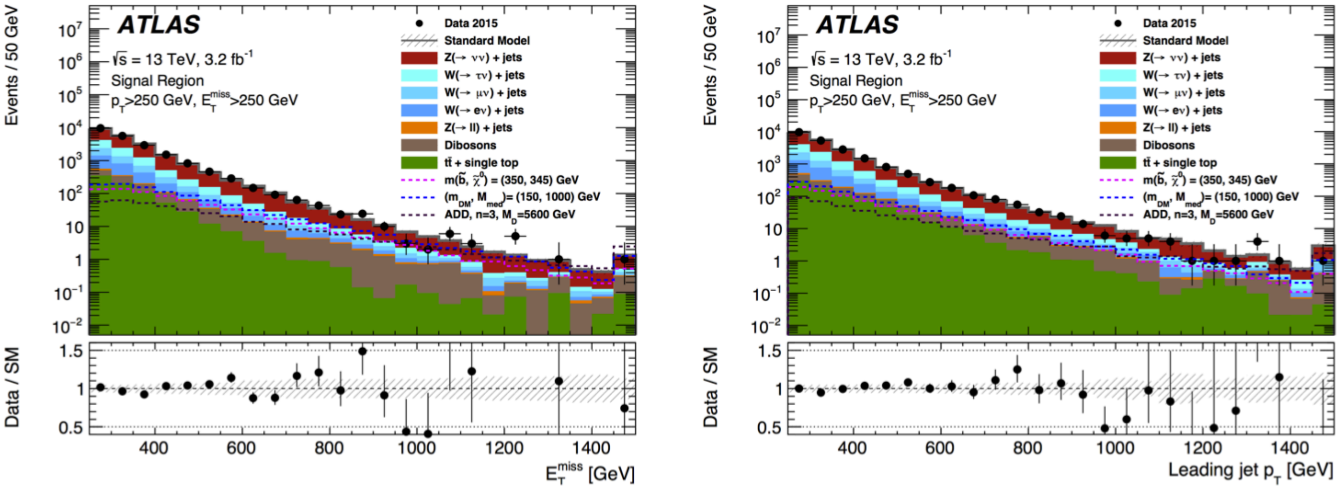
Backgrounds

One of the main difficulties is the control of the Z(νν) and W(lν – where the leptons is outside the acceptance)

Signal region

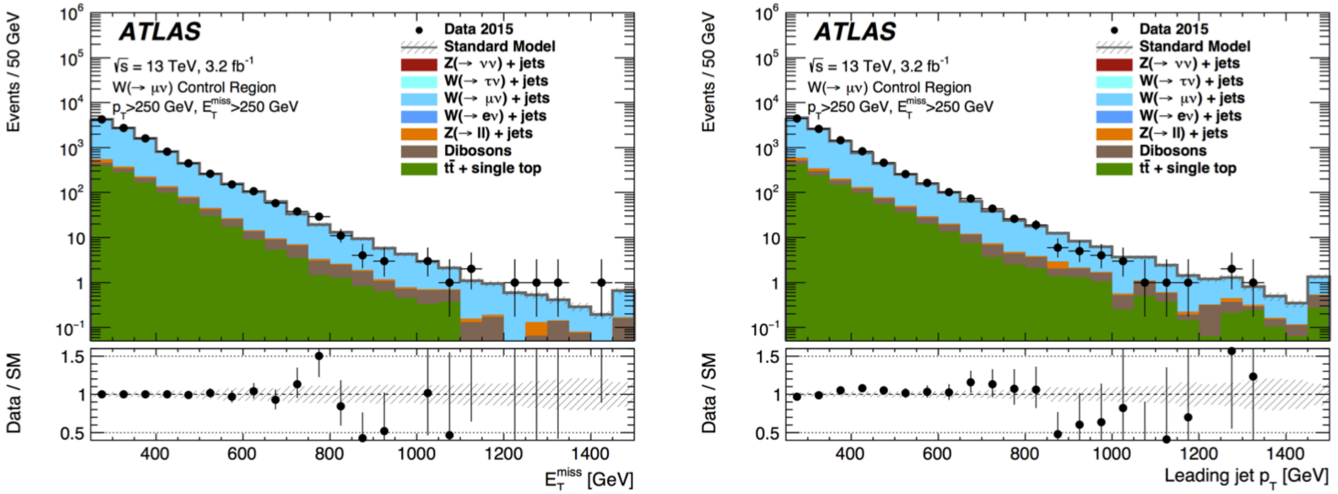
Excellent data-prediction agreement

Main background Z(νν)+jets and W(lν)+jets



Control region

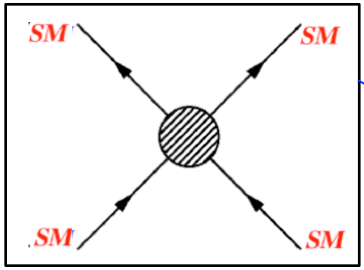
W+jets control region complements a lower statistics Z(ll) control region



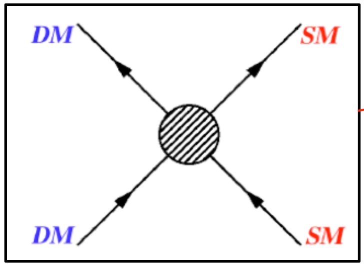
Analysis will rely on the W/Z ratio at high jet mometum

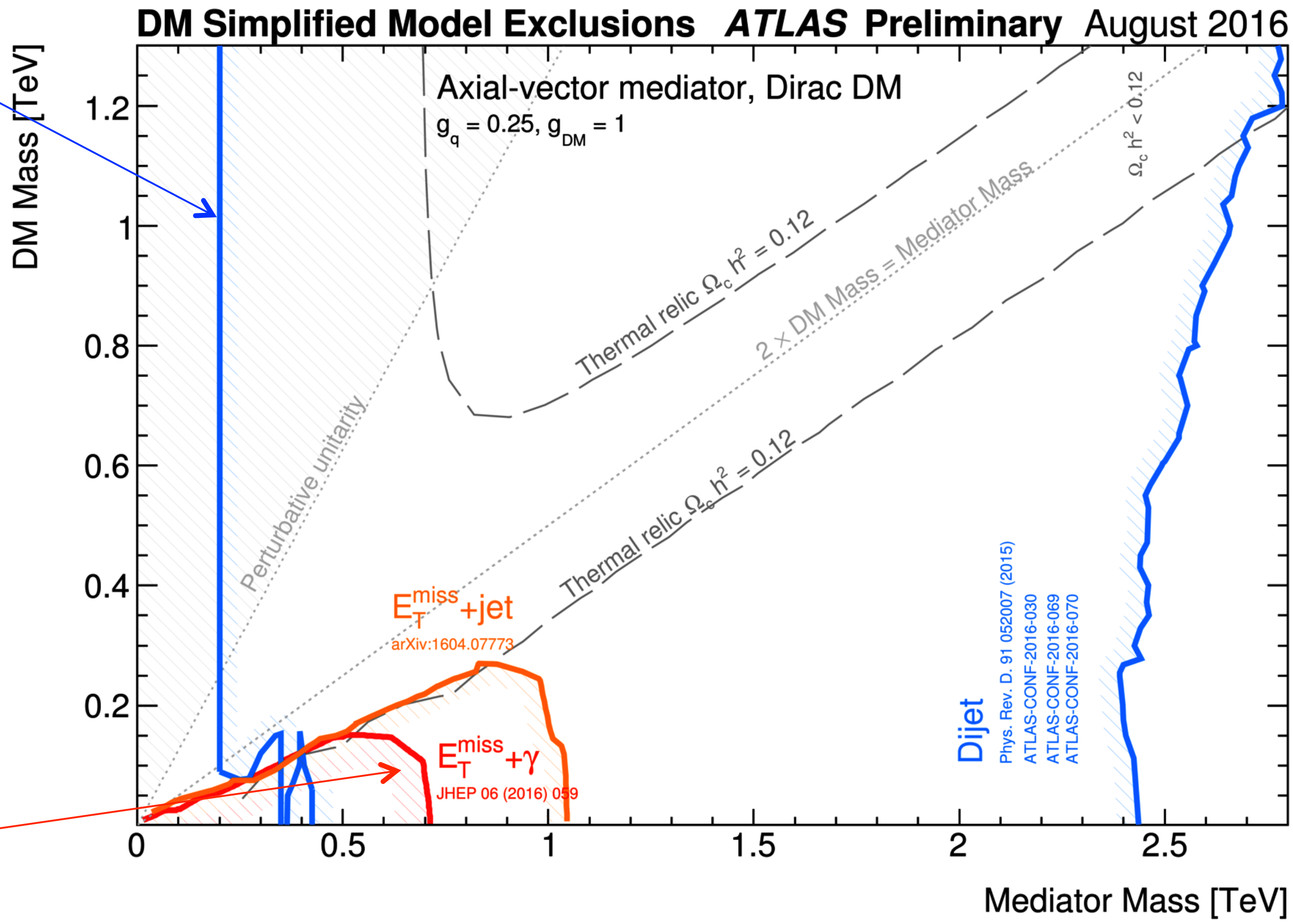
Interplay DM and Mediator Searches

Using the di-jet search down to the low mass range



Limits from direct searches of the mediator are mostly independent of the DM mass





Unconventional Signatures

Typical scenarios

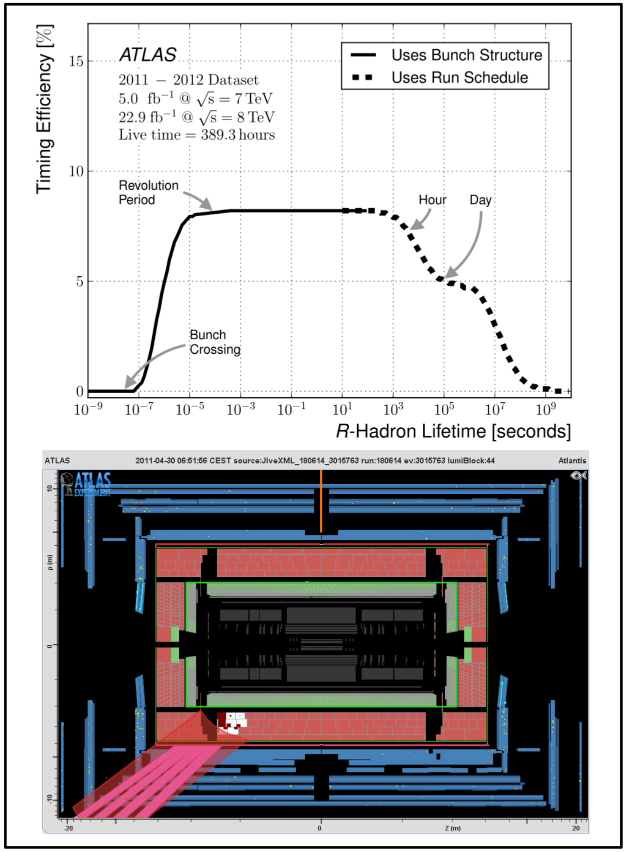
- Specific SUSY models
- Hidden valley models

Topologies

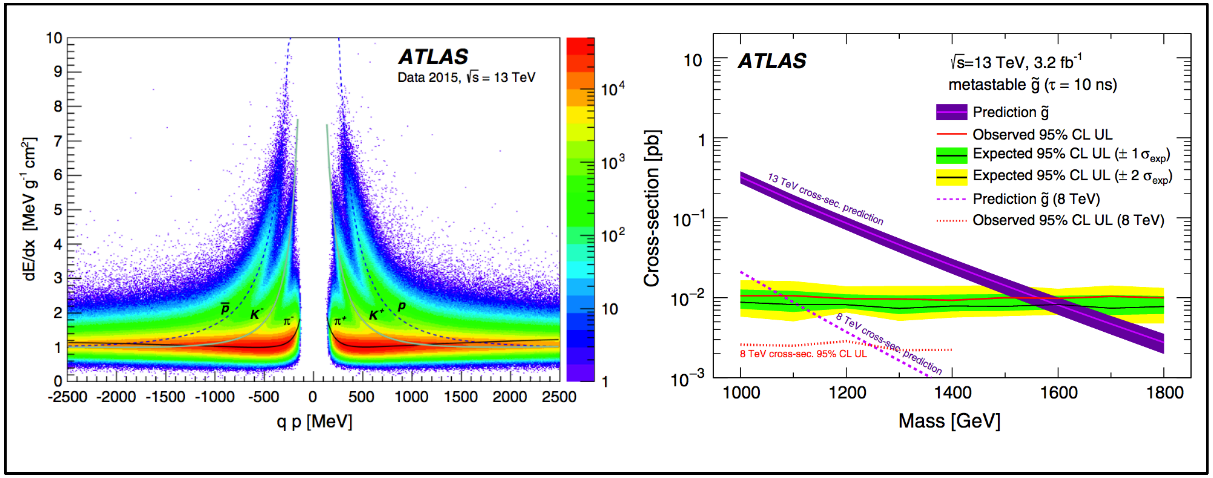
- Highly ionizing particles (using dE/dx)
- Out-of-time jets (R-hadrons)
- Highly displaced vertices
- Kinks in tracks
- Disappearing tracks
- High lepton multiplicities

These are very difficult analyses requiring specific non standard reconstruction algorithms.

Stopped Gluino Search

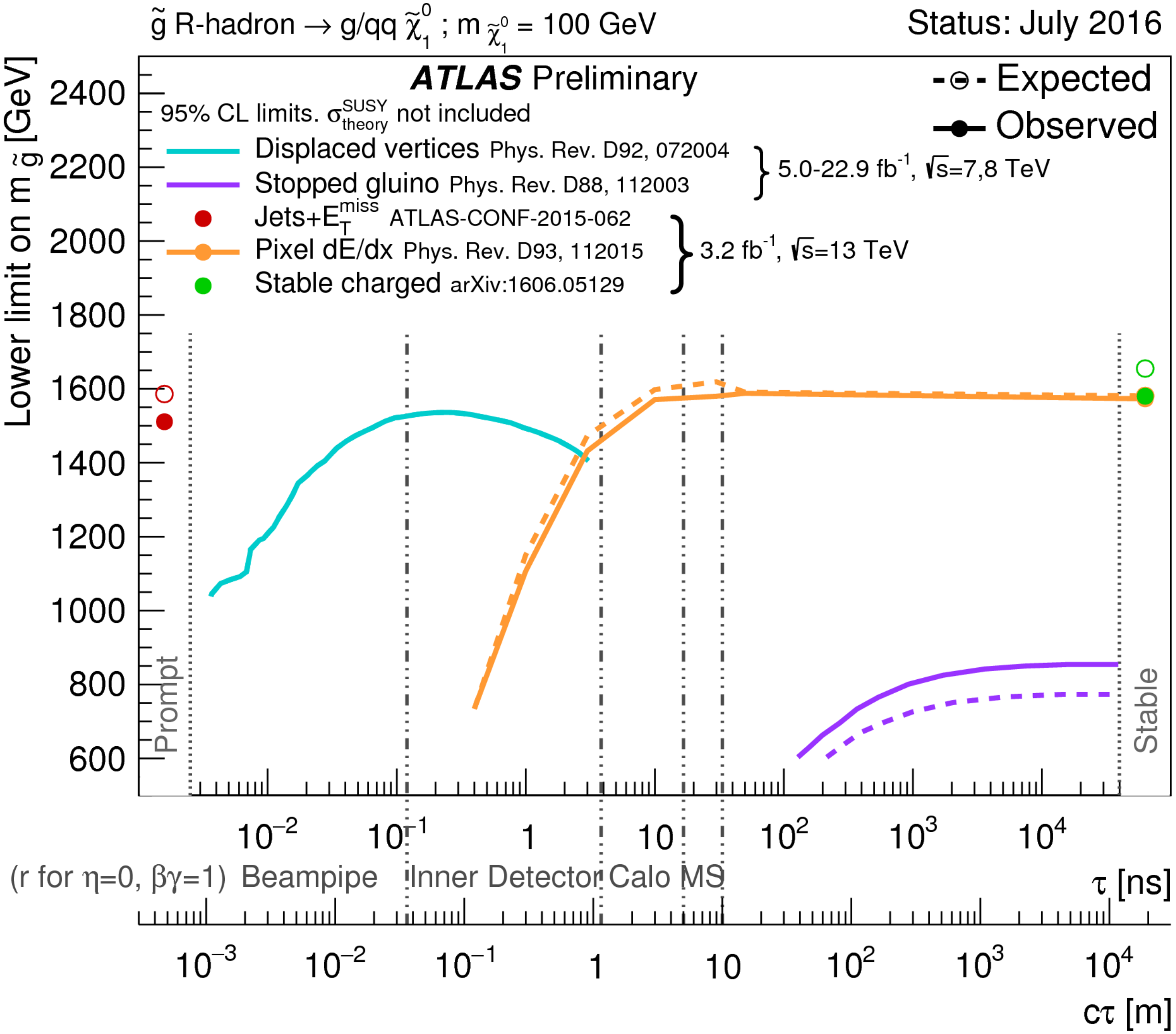


Pixel dE/dx search



Unconventional Signatures

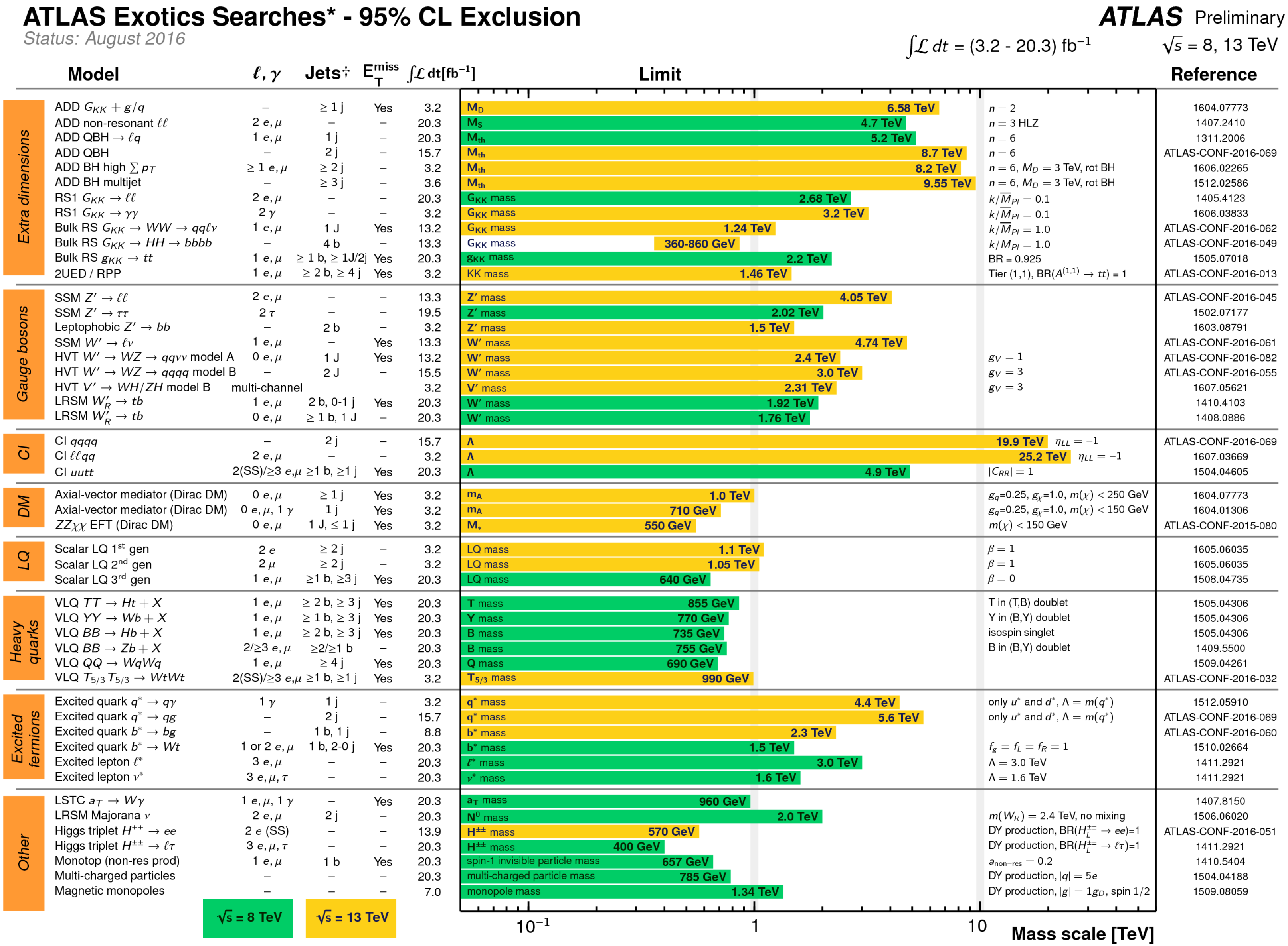
Overview of searches Run 2 in perspective: starting to cover ground for searches for LLP



Exotics Overview

Summary of searches Run 2 in perspective: very large ground covered still more to come!

Also illustrates the large number of searches not covered in this talk



ATLAS Exotics Searches* - 95% CL Exclusion

Status: August 2016

ATLAS Preliminary

$\int \mathcal{L}\,dt = (3.2 - 20.3)\ \mathrm{fb}^{-1}$ $\sqrt{s} = 8, 13$ TeV

	Model	ℓ, γ	Jets†	E_T^{miss}	$\int \mathcal{L}\,dt[\mathrm{fb}^{-1}]$	Limit		Reference
Extra dimensions	ADD $G_{KK} + g/q$	–	≥ 1 j	Yes	3.2	🟨 M_D 6.58 TeV	$n = 2$	1604.07773
	ADD non-resonant $\ell\ell$	2 e, μ	–	–	20.3	🟩 M_S 4.7 TeV	$n = 3$ HLZ	1407.2410
	ADD QBH $\rightarrow \ell q$	1 e, μ	1 j	–	20.3	🟩 M_{th} 5.2 TeV	$n = 6$	1311.2006
	ADD QBH	–	2 j	–	15.7	🟨 M_{th} 8.7 TeV	$n = 6$	ATLAS-CONF-2016-069
	ADD BH high $\sum p_T$	≥ 1 e, μ	≥ 2 j	–	3.2	🟨 M_{th} 8.2 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1606.02265
	ADD BH multijet	–	≥ 3 j	–	3.6	🟨 M_{th} 9.55 TeV	$n = 6$, $M_D = 3$ TeV, rot BH	1512.02586
	RS1 $G_{KK} \rightarrow \ell\ell$	2 e, μ	–	–	20.3	🟩 G_{KK} mass 2.68 TeV	$k/\overline{M}_{Pl} = 0.1$	1405.4123
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2 γ	–	–	3.2	🟨 G_{KK} mass 3.2 TeV	$k/\overline{M}_{Pl} = 0.1$	1606.03833
	Bulk RS $G_{KK} \rightarrow WW \rightarrow qq\ell\nu$	1 e, μ	1 J	Yes	13.2	🟨 G_{KK} mass 1.24 TeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2016-062
	Bulk RS $G_{KK} \rightarrow HH \rightarrow bbbb$	–	4 b	–	13.3	🟨 G_{KK} mass 360-860 GeV	$k/\overline{M}_{Pl} = 1.0$	ATLAS-CONF-2016-049
	Bulk RS $g_{KK} \rightarrow tt$	1 e, μ	≥ 1 b, ≥ 1J/2j	Yes	20.3	🟩 g_{KK} mass 2.2 TeV	BR = 0.925	1505.07018
	2UED / RPP	1 e, μ	≥ 2 b, ≥ 4 j	Yes	3.2	🟨 KK mass 1.46 TeV	Tier (1,1), BR($A^{(1,1)} \rightarrow tt$) = 1	ATLAS-CONF-2016-013
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	2 e, μ	–	–	13.3	🟨 Z′ mass 4.05 TeV		ATLAS-CONF-2016-045
	SSM $Z' \rightarrow \tau\tau$	2 τ	–	–	19.5	🟩 Z′ mass 2.02 TeV		1502.07177
	Leptophobic $Z' \rightarrow bb$	–	2 b	–	3.2	🟨 Z′ mass 1.5 TeV		1603.08791
	SSM $W' \rightarrow \ell\nu$	1 e, μ	–	Yes	13.3	🟨 W′ mass 4.74 TeV		ATLAS-CONF-2016-061
	HVT $W' \rightarrow WZ \rightarrow qq\nu\nu$ model A	0 e, μ	1 J	Yes	13.2	🟨 W′ mass 2.4 TeV	$g_V = 1$	ATLAS-CONF-2016-082
	HVT $W' \rightarrow WZ \rightarrow qqqq$ model B	–	2 J	–	15.5	🟨 W′ mass 3.0 TeV	$g_V = 3$	ATLAS-CONF-2016-055
	HVT $V' \rightarrow WH/ZH$ model B	multi-channel			3.2	🟨 V′ mass 2.31 TeV	$g_V = 3$	1607.05621
	LRSM $W'_R \rightarrow tb$	1 e, μ	2 b, 0-1 j	Yes	20.3	🟩 W′ mass 1.92 TeV		1410.4103
	LRSM $W'_R \rightarrow tb$	0 e, μ	≥ 1 b, 1 J	–	20.3	🟩 W′ mass 1.76 TeV		1408.0886
CI	CI $qqqq$	–	2 j	–	15.7	🟨 Λ 19.9 TeV	$\eta_{LL} = -1$	ATLAS-CONF-2016-069
	CI $\ell\ell qq$	2 e, μ	–	–	3.2	🟨 Λ 25.2 TeV	$\eta_{LL} = -1$	1607.03669
	CI $uutt$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	20.3	🟩 Λ 4.9 TeV	$\lvert C_{RR}\rvert = 1$	1504.04605
DM	Axial-vector mediator (Dirac DM)	0 e, μ	≥ 1 j	Yes	3.2	🟨 m_A 1.0 TeV	g_q=0.25, g_χ=1.0, $m(\chi) < 250$ GeV	1604.07773
	Axial-vector mediator (Dirac DM)	0 e, μ, 1 γ	1 j	Yes	3.2	🟨 m_A 710 GeV	g_q=0.25, g_χ=1.0, $m(\chi) < 150$ GeV	1604.01306
	$ZZ\chi\chi$ EFT (Dirac DM)	0 e, μ	1 J, ≤ 1 j	Yes	3.2	🟨 M_* 550 GeV	$m(\chi) < 150$ GeV	ATLAS-CONF-2015-080
LQ	Scalar LQ 1st gen	2 e	≥ 2 j	–	3.2	🟨 LQ mass 1.1 TeV	$\beta = 1$	1605.06035
	Scalar LQ 2nd gen	2 μ	≥ 2 j	–	3.2	🟨 LQ mass 1.05 TeV	$\beta = 1$	1605.06035
	Scalar LQ 3rd gen	1 e, μ	≥1 b, ≥3 j	Yes	20.3	🟩 LQ mass 640 GeV	$\beta = 0$	1508.04735
Heavy quarks	VLQ $TT \rightarrow Ht + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	🟩 T mass 855 GeV	T in (T,B) doublet	1505.04306
	VLQ $YY \rightarrow Wb + X$	1 e, μ	≥ 1 b, ≥ 3 j	Yes	20.3	🟩 Y mass 770 GeV	Y in (B,Y) doublet	1505.04306
	VLQ $BB \rightarrow Hb + X$	1 e, μ	≥ 2 b, ≥ 3 j	Yes	20.3	🟩 B mass 735 GeV	isospin singlet	1505.04306
	VLQ $BB \rightarrow Zb + X$	2/≥3 e, μ	≥2/≥1 b	–	20.3	🟩 B mass 755 GeV	B in (B,Y) doublet	1409.5500
	VLQ $QQ \rightarrow WqWq$	1 e, μ	≥ 4 j	Yes	20.3	🟩 Q mass 690 GeV		1509.04261
	VLQ $T_{5/3} T_{5/3} \rightarrow WtWt$	2(SS)/≥3 e,μ	≥1 b, ≥1 j	Yes	3.2	🟨 $T_{5/3}$ mass 990 GeV		ATLAS-CONF-2016-032
Excited fermions	Excited quark $q^* \rightarrow q\gamma$	1 γ	1 j	–	3.2	🟨 q* mass 4.4 TeV	only u^* and d^*, $\Lambda = m(q^*)$	1512.05910
	Excited quark $q^* \rightarrow qg$	–	2 j	–	15.7	🟨 q* mass 5.6 TeV	only u^* and d^*, $\Lambda = m(q^*)$	ATLAS-CONF-2016-069
	Excited quark $b^* \rightarrow bg$	–	1 b, 1 j	–	8.8	🟨 b* mass 2.3 TeV		ATLAS-CONF-2016-060
	Excited quark $b^* \rightarrow Wt$	1 or 2 e, μ	1 b, 2-0 j	Yes	20.3	🟩 b* mass 1.5 TeV	$f_g = f_L = f_R = 1$	1510.02664
	Excited lepton ℓ^*	3 e, μ	–	–	20.3	🟩 ℓ* mass 3.0 TeV	$\Lambda = 3.0$ TeV	1411.2921
	Excited lepton ν^*	3 e, μ, τ	–	–	20.3	🟩 ν* mass 1.6 TeV	$\Lambda = 1.6$ TeV	1411.2921
Other	LSTC $a_T \rightarrow W\gamma$	1 e, μ, 1 γ	–	Yes	20.3	🟩 a_T mass 960 GeV		1407.8150
	LRSM Majorana ν	2 e, μ	2 j	–	20.3	🟩 N^0 mass 2.0 TeV	$m(W_R) = 2.4$ TeV, no mixing	1506.06020
	Higgs triplet $H^{\pm\pm} \rightarrow ee$	2 e (SS)	–	–	13.9	🟨 $H^{\pm\pm}$ mass 570 GeV	DY production, BR($H_L^{\pm\pm} \rightarrow ee$)=1	ATLAS-CONF-2016-051
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	3 e, μ, τ	–	–	20.3	🟩 $H^{\pm\pm}$ mass 400 GeV	DY production, BR($H_L^{\pm\pm} \rightarrow \ell\tau$)=1	1411.2921
	Monotop (non-res prod)	1 e, μ	1 b	Yes	20.3	🟩 spin-1 invisible particle mass 657 GeV	$a_{\mathrm{non-res}} = 0.2$	1410.5404
	Multi-charged particles	–	–	–	20.3	🟩 multi-charged particle mass 785 GeV	DY production, $\lvert q\rvert = 5e$	1504.04188
	Magnetic monopoles	–	–	–	7.0	🟩 monopole mass 1.34 TeV	DY production, $\lvert g\rvert = 1g_D$, spin 1/2	1509.08059

🟩 $\sqrt{s}$ = 8 TeV 🟨 $\sqrt{s}$ = 13 TeV

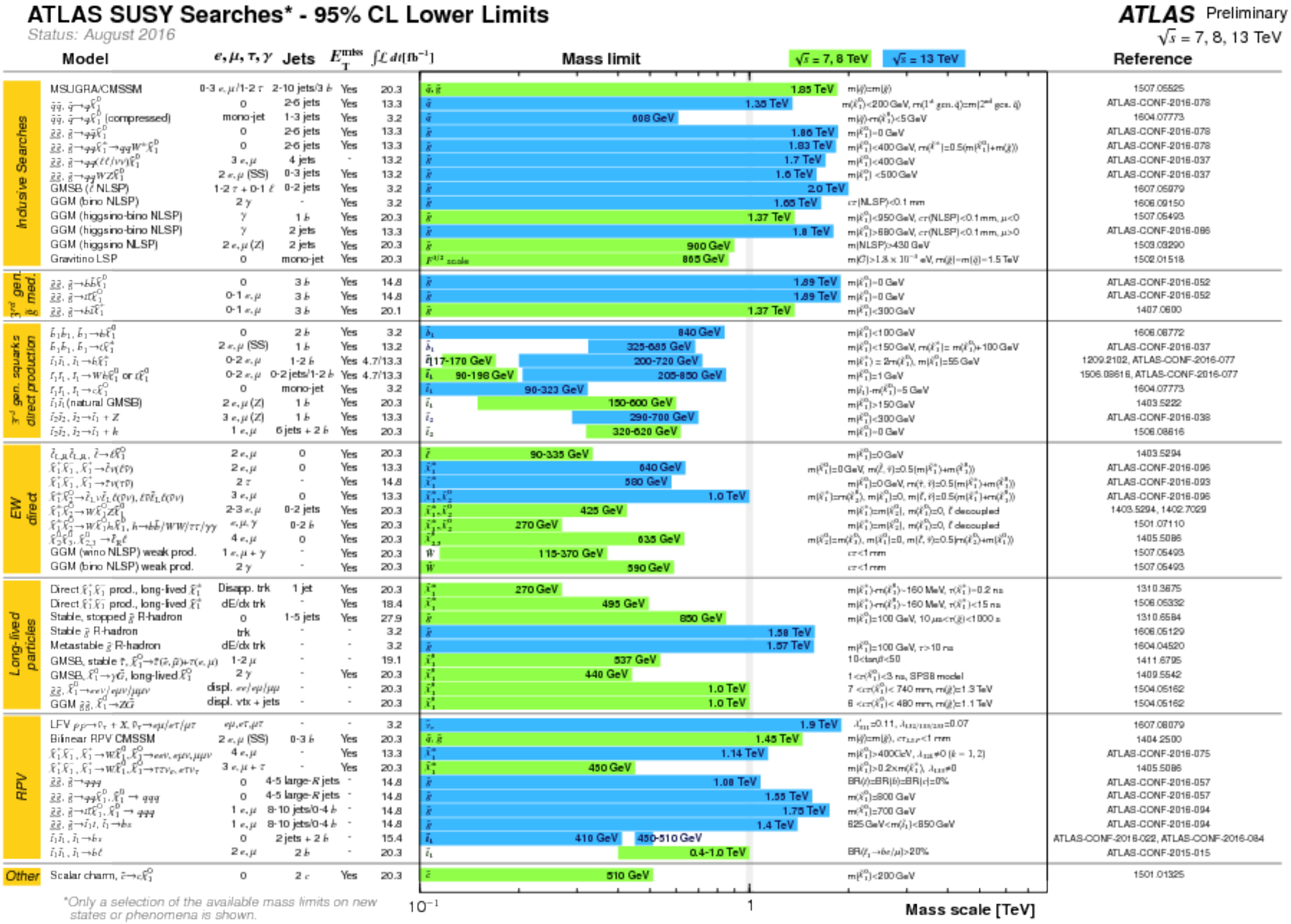
*Only a selection of the available mass limits on new states or phenomena is shown. Lower bounds are specified only when explicitly not excluded.

†Small-radius (large-radius) jets are denoted by the letter j (J).

SUSY Overview

Summary of SUSY Run 2 in perspective: very large ground covered still more to come! Main analyses and in compressed scenarios.

Also illustrates the large number of searches not covered in this talk



Mini Searches Overview

No significant excess has been observed so far

Non significant excesses to keep an eye on:

- CONF-050 Stops 1L: In (4J, 1b, high MET) 3.3σ (No excess in CMS)
- CONF-083: V(W)H (Full hadronic boosted): 3.5σ (2.5σ global) at 3 TeV
- CONF-084: Paired dijet local 2.6σ (2.1 σ global) at 870 GeV
- CONF-079: Four leptons high mass 2.9σ (1.9 σ global) at 705 GeV
- CONF-058: ttH ML in SS-0τ and SS-1τ not significant but excesses at Run-1 in ATLAS and CMS
- EXO-16-015 PAS γ-jet high mass 3.7σ (2.8 σ global) at ~2 TeV (not seen in ATLAS with similar luminosity JHEP03 (2016) 041)
- LFV Higgs decays to $\tau\nu$

Dig deeper (a few concluding remarks)

The current results on the Run 2 dataset are just a (small) fraction:

- 30% of the already available data
- 10% of the total Run 2 dataset
- 1% of the total HL-LHC data

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How to dig deeper? Manifesto for precision, improving: Modeling, generation, simulation of increasingly complex processes. Crucial interaction with TH - PH community.

Where to dig deeper? Everywhere possible… Crucial interaction with TH – PH community.

Thank You!